Increasing Health System Resilience During Times of Crisis: Application of Systems Thinking & Creative Problem-Solving Methodologies

A DISSERTATION SUBMITTED TO THE FACULTY OF THE UNIVERSITY OF MINNESOTA BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSPHY

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December 2020

Acknowledgements

I received a great deal of support throughout the research and the writing of this dissertation. I owe an enormous debt of gratitude to the following people, without whom I would not have been able to complete my doctoral degree. I hope that the findings from my research will make a lasting impact on the way we think about and address outbreak response and the resilience of health systems.

I would first like to thank my advisor, Dr. Michael Osterholm, and the members of my committee, Drs. Ruth Lynfield, Bruce Alexander, and Jeff Bender. Their expertise and advice was invaluable and their insightful feedback allowed me to bring my work to a higher level. I would also like to thank Drs. David Boulware and Daniel Bausch for their continued mentorship in the field of infectious disease and outbreak response.

I am deeply grateful for my colleagues and collaborators in Congo-Brazzaville, Democratic Republic of Congo, Guinea, Liberia, Nigeria, and Sierra Leone, who worked tirelessly during three major outbreaks and believed in the utility of the methodologies that we tested. I also owe a great debt to the patients, patients' families, and their communities, for they allowed me to enter into their homes and lives to truly understand the impact that outbreaks can have. I would specifically like to thank the following co-authors: Drs. Rifat Atun, Suman S Majumdar, Eric Nilles, Anita A Shah, Mamadou Harouna, Djingarey, Pierre Formenty, Chikwe Ihekweazu, James Banjura, Benoit Kebela, Adesola Yinka-Ogunleye, Ibrahima-Soce Fall, Womi Eteng, Mohamed Vandi, Charles Keimbe, Anwar Abubakar, Abulazeez Mohammed, Desmond E Williams, Michael Osterholm, Margaret Lamunu, Sylvie Briand, Daniel G Bausch, Jean Claude Changa, Etienne Minkoulou, Dan Jernigan, Demba Lubambo, Asheena Khalakdina, Ibrahim Mamadu, Ambrose Talisuna, Albert Mbule Kadiobo, Amara Jambai, Bruce Aylward, Junxiong Teo, Luke Bawo, Sakoba Keita, Dhamari Naidoo, Shalini Singaravelu,Ali Ahmed Yahaya, Beatrice Muraguri, Brice Ahounou,Victoria Katawera, Fredson Kuti-George, Yacouba Nebie, T. Henry Kohar, Patrick Hardy, David Kargbo, Nuha Mahmoud, Yewondwossen Assefa, Orla Condell, Magassouba N'Faly, Leon Van Gurp, Julia Ryan, Boubacar Diallo, Foday Daffae, Dikena Jackson, Fayyaz Ahmed Malik, and Philomena Raftery.

I would like to thank my supervisors at the World Health Organization, Drs. Bruce Aylward, Pierre Formenty, Maria Van Kerkhove, and Asheena Khalakdina, for encouraging me to pursue a doctoral degree while working under their leadership.

In addition, I am thankful for Duncan Downes, Katie Smallwood, Meghan Bohren, Dhamari Naidoo, Shalini Singaravelu, Vanessa Brizuela, Helena Ardura Garcia, Sofia Baliño, Kathryn Chelminski, Andrea Wachowiak, Mary Kay Hanson, and a long list of other friends for providing countless hours of advice, support, and laughter.

Lastly, I would like to thank my family for their wise counsel, unconditional support, and sympathetic ears. To my parents, thank you for always being there for me, fostering my curiosity, and encouraging me to push my limits. I could not have completed this dissertation without your continued love, support, encouragement, and guidance.

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Dissertation Structure

My dissertation has five chapters with supplemental figures and charts located at the end. The first chapter, "The Need for a Paradigm Shift," is an introduction to the broad landscape and challenges in this emerging area and discusses the need for a paradigm shift in public health; one where we systematically address health system strengthening activities during the acute phase of health emergencies. The chapter, "Building a Foundation," provides insight into the challenges for this specific body of work and describes the questions and methodologies that I explored. Chapters Three and Four highlight specific examples of methodologies that can be implemented during outbreak response. Chapter three, "Systems Thinking Methodologies: Process Mapping," details an application of process mapping, a systems thinking methodology, during three unique contexts. This provides detailed steps of how to perform the methodology, lessons learned and recommendations for future applications. Chapter four, "Creative Problem-Solving Methodologies," describes the application of a creative problem-solving methodology, design thinking, in three countries over the course of one outbreak. This chapter also details the data collection and reporting system which was the outcome of the design thinking exercise. The chapter outlines how design thinking was used during the outbreak along with lessons learned and recommendations for future implementation. Further, it explains how the data collection and reporting system was developed using the design thinking methodology and details how it was implemented, including associated challenges and lessons learned. Chapter five, "Conclusion and Next Steps," summarizes the major findings and contributions to science, highlights additional research that should be conducted to provide further evidence to this growing field, and provides policy recommendations.

Chapter 1: The Need for a Paradigm Shift

Disease outbreaks and health emergencies cause substantial human suffering, death and economic loss. Such events push weak health systems to a breaking point, as witnessed during recent outbreaks of cholera, drug-resistant tuberculosis, Ebola virus disease, and Zika virus disease. (1–4) The current COVID-19 pandemic is testing the response and resilience of health systems worldwide, including well-resourced systems in Europe and North America, where health institutions and public health agencies are operating beyond capacity, diagnostics are lacking, triage systems are faltering, personal protective equipment are insufficient, and frontline health workers are facing risks of disease and death. (5)

Building responsive and resilient health systems is an imperative for the global health community. A resilient health system can absorb the shock of an emergency while continuing to provide regular health services. (6–8) Most frameworks for building resilient health systems that effectively respond to disease outbreaks focus on enhancing preparedness or response capacity *prior* to an emergency, (9–11) or to strengthen health systems *after* the emergency, typically during the recovery phase. Indeed, many aspects of outbreak response lay the groundwork for health systems strengthening, such as enhancing surveillance systems and training the health workforce. (12) Over the last two decades, numerous mechanisms, frameworks and agreements have been developed to promote health systems that are resilient to outbreaks and major health emergencies, such as the International Health Regulations (IHR) – an agreement between 196 countries to work together to mitigate global health security threats and a cornerstone of efforts aimed at ensuring sufficient health system infrastructure to detect, assess and report major events impacting public health. (13) Through the IHR, in 2016 the Joint External Evaluations (JEE) were created to identify critical gaps within health systems and prioritize actions to enhance preparedness and response within a country. (14)

There is not yet a framework, toolkit, or formalized targets for health system strengthening (HSS) activities during outbreaks. While these activities are already taking place during response efforts, they are often considered low priority among a host of challenges, and/or are given limited financial support. There remains an opportunity to more systematically strengthen health systems *during* outbreak response (particularly in the early to mid-stages) when there is heightened attention and available resources. Here, I discuss the need for a paradigm shift to include health system strengthening as a key component integrated into outbreak response and provide insights into how this shift can be accomplished, with particularly important implications for the current COVID-19 pandemic and future acute health emergencies of its kind.

During outbreaks, ministries of health and other national and international responding organizations are routinely provided with financial and/or human resources support by internal or external funding bodies. Resource allocation is varied but usually includes support for surge staff, information systems, diagnostic tests, vaccines, treatment centers, operational research, risk communications and community engagement, to name a few. For example, during the current COVID-19 pandemic the United States of America approved a $2 trillion-dollar stimulus bill, of which $157 billion was directly allocated to the health system and research. (15) During the 2014-2016 Ebola outbreak in

West Africa the US and UK governments spent $2.4 billion and $363 million, respectively. (16) Further, the US government allocated $7.65 billion to the health response during the 2009 H1N1 outbreak. (17) While it is critical and ethically necessary to prioritize immediate response activities, the organizational infrastructure, capacity and networks which typically result from these investments could be leveraged to also strengthen health systems, in particular those components that are directly impacted during the outbreak, such as health information systems, healthcare services, medical and public health workforce, supply chain management, and essential medicines and vaccines. Strengthening these components during the acute response may require additional resources but, in the long-term, would likely result in cost-savings when system efficiency and effectiveness improve. This approach would strengthen the health system, promote sustainability of the emergency investment and increase resilience against future emergencies.

An on-going challenge is to ensure the sustainability of the investments post-response. Lessons could be learned from industries, such as military, nuclear, oil, gas and aviation that have similar high-pressure and complex environments as the biomedically-oriented institutions and experience major events and disasters, and have used methodologies to effectively address acute challenges while building better, more sustainable systems and processes along the way. (18) Methodologies like systems analysis and applied systems thinking could be adapted and utilized during an acute response to both further enhance response effectiveness and strengthen health systems. (18)

I identified ten activities that could be implemented during health emergencies to ensure that health systems are strengthened during the response. While some activities can be applied on subnational and national levels, others may be best suited to regional or international scales.

(i) Inclusion of health systems experts in Emergency Coordination Centres, or country equivalent, from the onset of the emergency response

(ii) Ensuring that response teams, usually and appropriately multidisciplinary, include personnel with the skills to assess and incorporate elements of health systems strengthening into the response, such as project managers, data analysts, engineers, and experts in health systems and applied system methodologies

(iii) Developing a network and community of thought leaders and/or contributors who can provide support and innovative ideas for health systems strengthening during outbreaks. Examples of effective networks in related domains include the R Epidemics Consortium (www.repidemicsconsortium.org/) and the World Health Organization's Emerging Diseases Clinical Assessment and Response Network (www.who.int/csr/edcarn/en/)

(iv) Developing a toolkit focused on strengthening health systems during an outbreak, including metrics of health system performance, in order to provide guidance for outbreak response teams to ensure health systems strengthening actions are considered as a priority when responding to outbreaks

(v) Developing a cadre of health professionals with expertise in both health systems strengthening and outbreak response to integrate these activities

(vi) Conducting operational and implementation research during health emergencies to understand which interventions, strategies and tools provide the best outcomes for both the acute response and strengthening of health systems and to facilitate immediate policy relevance and scalability

(vii) Adjusting already existing HSS frameworks to provide guidance for outbreak response settings and developing the associated performance metrics

(viii) Including funds for health systems strengthening in outbreak response budgets. While this would increase short-term costs, these would likely be easily offset by the future gains that strengthened health systems would provide in disease prevention

(ix) Targeting communications and advocacy efforts to appeal to political leaders and affected communities, highlighting the importance of health system resilience and the need to focus on associated activities during health emergencies

(x) Aligning outbreak response activities with HSS goals to ensure acute response challenges are met while also ensuring sustainability of efforts

Several conditions will enable the adoption of such an approach. These include strong national leadership and governance, donor-partner and national policies designed to absorb an influx of funds during the response for both acute and long-term systems strengthening activities, including the prioritization of funding to activities that support both activities, good communication and support between the teams involved in the outbreak response and health systems strengthening activities, open sharing of data and other relevant information to allow for integrated solutions, and a growth mindset. Furthermore, institutional support and buy-in from partners involved in the response is crucial to ensure that funding is available to sustain the activities both during the acute emergency and afterwards.

Outbreaks, which create uncertain, complex and dynamic environments, provide an opportunity to adopt systems thinking (19) and new approaches to simultaneously effectively strengthen health systems during the response. Furthermore, they serve as catalysts for garnering both political and public support for health systems strengthening efforts. The COVID-19 outbreak presents such an opportunity, as critical health system bottlenecks are being exposed in high-, middle-, and low-income countries alike. In a globalized society in which diseases with epidemic and pandemic potential are increasing, a paradigm shift is needed to ensure that every opportunity is used to ensure a rapid, effective response to the current threat while building responsive, resilient and sustainable health systems that keep populations healthy in the long term.

Chapter 2: Building a Foundation

Established Approaches

The outbreak response continuum demonstrates the interconnectedness and importance that preparedness, response and recovery play in ensuring populations and health systems remain resilient during a crisis (20). This concept, while not new, has within the last decade resulted in a growing body of work particularly in the preparedness and recovery phases.

In relation to the preparedness phases, following the Ebola crisis, the World Health Organization (WHO) along with partners ideated and implemented the JEE under the IHR framework. (13,14) Further to this, Blanchett, et al. developed a conceptual framework on governance and capacity to manage resilience of health systems. (9) Kruk et al. developed a resilient health systems framework based off resilience in other disciplines (11) and the National Academies of Sciences, Engineering, and Medicine developed the Global Health Risk Framework: Resilient and Sustainable Health Systems to Respond to Global Infectious Disease Outbreaks. (10) In addition, in 2016, two major symposiums and workshops were conducted focusing on building resilient and responsive health systems. (10, 21)

There has also been strong support for using disasters as a trigger to build more resilient nations and societies during recovery phases through the development of Frameworks such as 2015 Sendai Framework. This framework focuses on the re-building and recovery of societies post-disaster including physical restoration of infrastructure, revitalization of livelihood and economy/industry, and the restoration of local culture and environment. (22,23) In addition, the "Essential Public Health Services Framework of 1994" was adapted to focus on rebuilding communities through the "Disaster Recovery Framework". Further the "WHO Recovery Toolkit" was created to support countries to achieve health service resilience (12,24,25). Tools such as the "One Health Systems Mapping and Analysis Resource Toolkit (OH-SMART)" were developed and implemented during after-action reviews (26).

Yet, to date, there are no frameworks or toolkits which detail how to strengthen health system resilience during the response phase of health emergencies. Similarly, there has been limited systematic prioritization of resources or activities *during* outbreak response to strengthen health systems. As outlined, there are numerous well-established frameworks which could be adapted to provide guidance for outbreak response settings. If adaptation is not feasible, a framework specific to response work could be developed. Further, developing a toolkit which provides guidance for response teams on how to ensure health system strengthening activities are incorporated into the response could support this shift. However, without evidence, it is challenging to develop and/or adapt frameworks, toolkits and polices.

Problem Statement

The significant impact that health emergencies have on morbidity and mortality of populations coupled with the influx of human and financial resources during the acute crisis and the need for resilient and responsive health systems that can withstand the shocks of the emergency ***requires*** novel approaches and solutions. While each outbreak has its own unique set of characteristics and challenges; the overarching similarities related to systems (i.e., surveillance, laboratory, clinical, etc.) being pushed beyond capacity are many and could be systematically improved during the outbreak through evidence-based approaches and methodologies. Yet, an important opportunity is currently being missed to do this during the response as there is limited evidence that highlights how we can do so effectively. My research aims to lay the foundation for future work in this area through the piloting of two separate methodologies.

Research Methodologies

To achieve my objectives, I piloted systems thinking and creative problem-solving methodologies over the course of three years and multiple outbreaks to answer the following research questions:

i. How can systems thinking be used in outbreak response to streamline response efforts and contribute to health system resilience.

ii. How can creative problem-solving methodologies be used during an outbreak response to create a solution that is useable during and after the response.

Systems thinking is an approach to understand and improve complex issues and situations (27). It can be defined as a "set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects" (28). Creative problem-solving is a way of solving problems or identifying opportunities when conventional thinking has failed. It encourages the user to identify fresh perspectives and create innovative solutions in order to overcome obstacles and reach the identified goals (29).

After conducting a thorough review of systems thinking and creative problem-solving methodologies and approaches used in similar high-stake industries, I decided to specifically pilot process mapping and design thinking methodologies. Process mapping is a systems thinking methodology which provides a graphical representation that helps others visualize the details of the process in order to identify challenges and guide decision making (30). Design thinking is a creative problem-solving methodology that can be defined as "a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test." It encourages users to focus on the people they are creating for, which leads to better products, services, and internal processes (31,32). I chose these specific approaches as they have proven success in other industries, have documented use-cases in healthcare and public health, have a low-cost of implementation, and have a low barrier to entry requiring minimal training. Additionally, they are collaborative methodologies, which is particularly important during outbreaks and health emergencies when health systems are being pushed to their limits.

Success of the methodologies were measured through multiple metrics. The effectiveness and usefulness of the process mapping methodology in each country was evaluated on one specific process or outcome indicator as determined in collaboration with the Ministry of Health (MoH) at the time the exercise was conducted. In Sierra Leone, the indicator was time from laboratory samples being taken to time the results reach the intended audience. In the Democratic Republic of Congo, the indicator was time from suspect case being identified to the time the Incident Management System (IMS)/MOH was notified. In Nigeria, the indicator was time the suspect case was identified to time the national level of Nigeria Centres for Disease Control (NCDC) received the Case Identification Form (CIF) and case pictures. The metrics are detailed in Chapter 3. The success of the design thinking methodology was primarily determined by the creation and usefulness of the data collection and reporting system to monitor the response and make strategic decisions. The involvement of end-users was measured post-implementation of the data collection and reporting system. This was done through assessing the accuracy and timeliness of the data being collected by data collectors and epidemiologists and through measuring the collaboration and involvement of laboratories by counting how many labs out of total the labs responding were sending data to the system. Further, I evaluated whether the data from the system were being used by stakeholders through measuring how often the data were used in presentations to leadership and general public and/or requests for access for research purposes. These metrics are further detailed in Chapter 4.

Significance and Innovation of Research

Both systems thinking and creative problem-solving methodologies have demonstrated results as well as lessons learned for future implementation. My research shows that despite the chaos and complexities associated with emerging pathogen outbreaks, the implementation of the aforementioned methodologies can address immediate response priorities while simultaneously strengthening components of a health system

The process mapping exercises were conducted in Sierra Leone during an Ebola outbreak, in Democratic Republic of Congo during a yellow fever outbreak and in Nigeria during a monkeypox outbreak. Each country saw drastic improvements in system functioning. In Sierra Leone, laboratory results reached the intended audience in 24 hours instead of six days. In the DRC, the time it took to be notified of a suspected case of yellow fever was reduced from seven to three days. In Nigeria, key data reached the national level in 48 hours instead of five days.

Further, the design thinking principles implemented in Sierra Leone, Liberia and Guinea were used to develop a data collection and reporting system which contains all laboratory data from the three countries during one of the most complicated multi-country outbreaks to date. The data collection and reporting system was used to orient the response interventions at the district, national, and international levels within the three countries including generating situation reports, monitoring the epidemiological and operational situations, providing forecasts of the epidemic, and supporting Ebola-related research and the Ebola National Survivors programs within each country.

Aside from effectively addressing critical needs during the height of the outbreaks, these approaches have been valuable in building system resilience. In fact, to date, these are the first documented approaches of using systems thinking and creative problem solving to address acute challenges during the outbreak while strengthening health system resilience. These methodologies are particularly useful as they can be applied to any country that has an outbreak. Second, there is an acute need in the global health community to respond to disease outbreaks in a way that effectively uses limited resources. Using methodologies that allow for the acute challenges to be addressed, while identifying and supporting the strengthening health systems and enabling optimization of resources (both human and financial) is critical. Third, this is a user-friendly and low-cost methodology that can be implemented by a plethora of individuals during any timepoint of an outbreak, including during preparedness and readiness activities.

Chapter 3: Systems Thinking Methodologies: Process Mapping

BACKGROUND:

Process mapping is a systems thinking approach used to understand, analyze, and optimize processes within complex systems (33) Process maps were first introduced in the early 1920's, (34) however it was not until the 1980's that frameworks and methodologies which brought together various disciplines such as architecture, design, and engineering were developed. This participatory methodology promotes collective thinking, facilitates communication among stakeholders, and provides visualization of challenges. (35)

To date, process mapping during outbreaks has not been documented, although it has been applied in the health systems and healthcare field. It has been used to ensure optimization of civil registration and vital statistics systems and in various health care quality improvement projects, from mapping the patient journey in a healthcare facility to redesigning procedures to increase efficiency in the United States of America and the United Kingdom. (33,36–38) It was used in South Africa to understand how the utilization of point of care tests for STI, TB, and HIV impacted care at large urban public healthcare clinics. (39) Additionally, process mapping has been used to improve collaboration at the human-animal interface across a variety of sectors through the OH-SMART toolkit.(40)

Process mapping visually clarifies stakeholders' relationships and identifies bottlenecks, inefficiencies, and design flaws that limit system performance. (35) It can therefore be a useful tool for effective outbreak response when health systems become overloaded and basic health services cannot be maintained, allowing existing processes to be streamlined and strengthened instead of creating new ones. Mapping processes allows interactions, gaps, and redundancies within the health system to be identified, captures complexities effectively, and brings people together to share a common view of the system, which are useful for developing solutions that can improve acute challenges as well as the long-term functionality of a health system. (35) This methodology can support countries to leverage the incoming resources during response and recovery efforts, thus facilitating short and long-term health system strengthening. The flexibility of the methodology lends itself to being implemented in low, middle- and high-income countries alike and may be useful to address many of the operational complexities of the COVID-19 pandemic.

Process mapping exercises, which have proven to be an effective tool at optimizing processes in other disciplines, can be a useful tool to assist with specific challenges during outbreak response. I aim to demonstrate how this methodology can be applied during any phase of a disease outbreak response so that processes can be streamlined to improve the current outbreak response as well as the long-term challenges in the information, clinical, and laboratory systems.

CONDUCTING PROCESS MAPPING EXERCISES:

Process mapping exercises were conducted during three unique disease outbreak contexts in Sierra Leone, the Democratic Republic of Congo (DRC), and Nigeria between 2014-2017. Each mapping exercise followed the same four-step methodology but had a unique focus based on the specificities of the disease outbreak, country context, and health system. All addressed a challenge related to the health system either not functioning at an optimal level, or being overwhelmed by the outbreak, or both. The process mapping methodology I used was adapted from the operations management discipline (41,42) and was aligned with Savigny, *et al.'s* "Applied Systems Thinking for

Health Systems Research: a methodological handbook" (35) to fit the context of a disease outbreak. (Figure 1). This adaptation was done to account for the limited time and resources available during an outbreak as they are dynamic and require quick interventions. One person with strong leadership, facilitation and coordination skills led the exercise and an additional one to two people (depending on the country and context) helped conduct the interviews.

Preparation

In step one, which took a few hours, big-picture operational challenges were identified with senior leadership and the incident manager. Engagement and buy-in from senior leadership within the Ministry of Health or National Disease Control units is essential. Then the goals and objectives for each process mapping exercise were defined according to challenges of each outbreak. Indicators were identified to measure the effectiveness of the process re-design. The indicators collected varied according to the process being mapped and the operational context in which the outbreak was occurring. Organizations, partners and stakeholders who were impacted by or involved with the process were also identified.

Conduct interviews

Next, individual interviews lasting up to one hour were conducted with all persons identified during step one. Stakeholders were encouraged to provide honest and constructive opinions during the discussions. Interviews focused on obtaining specific knowledge regarding the step-by-step process related to the main operational challenge being mapped including obtaining an understanding of their specific responsibilities and roles, the roles and responsibilities of their colleagues, challenges that they encounter within the health system, barriers that prevent the health system from operating at an optimal level, barriers that prevent the current response from operating at an optimum level, specific “pain points” (i.e., challenges) in the current process, and general systematic challenges that impact the process. If stakeholders not initially identified during step 1 were mentioned as instrumental to the process, they were also contacted and interviewed.

Map and analyze

Next, each step in the process, as documented during the interviews, was drawn out and visually mapped with pen and paper. Prior to the group re-design session this was put into an electronic format to improve legibility for all stakeholders.

Validate and Co-Create

A group re-design session was then held with all stakeholders to validate the process map and to ensure there were no missing pain points or challenges in the process. Solutions were ideated and then prioritized according to the costs and length of time to implement them, availability and willingness of persons and organizations to implement and monitor changes, and perceived benefit to the response and health systems. This phase served to bring all parties to a common understanding of the challenges and to co-create solutions which would improve the response and contribute to the strengthening of the health system. Implementation of changes began immediately after the re-design session and were measured approximately 7-10 days later. Implementation was performed by partners and stakeholders involved in the process mapping exercise according to their mandate and/or interest in the solution. I did not fully implement the re-design in any of the case studies as this required human and financial resources; therefore, the indicators described are base-line and post-mapping exercise, pre-full implementation.

CASE STUDY 1: EBOLA IN SIERRA LEONE

Ebola virus causes a severe disease with average case fatality rate of 50%. (43) It is a zoonosis which spreads in rare events from animals to humans and then is sustained in the human population through human to human transmission. (43) An Ebola virus disease (EVD) outbreak was reported for the first time in Sierra Leone's history in June 2014. This context rendered a complex response which was further compounded by a weak health system, limited surveillance and laboratory capacity, few hospitals and clinics with appropriate isolation facilities, an urban setting with overcrowding and poor sanitation, and general population distrust of the government. (44,45) The first Ebola case was reported in early June in Kailahun District, over 250 miles from Freetown, the capital of Sierra Leone. (46) This resulted in the largest known Ebola outbreak to date with over 14,124 cases and 3,956 deaths in Sierra Leone alone. (47)

The process mapping exercise was conducted in Freetown, Sierra Leone in December 2014 to address the challenges associated with an urban outbreak. The process mapping exercise was conducted over the course of three days, six months after the first cases had been identified in Freetown. The outbreak ended March 17, 2016. (47) At this time, Western Area, the province in which Freetown is located, had 40% of the confirmed EVD cases in the country with approximately 26 confirmed cases and 82 new, suspected cases each day. (48) There were 5 laboratories and 13 Ebola Treatment Units

(ETUs) and Holding centers (HCs) providing services for Western Area at this time. Due to capacities in Western Area being overloaded, patients and/or samples were transferred to other districts accordingly.

The objective of the process mapping exercise was to understand why there were delays in obtaining patient results. These delays were impacting the entire response: patient treatment, case investigation and contact tracing teams, quarantine units, families, and overall outbreak coordination. The exercise was conducted with Ministry of Health officials with support from the WHO and Centers for Disease Control and Prevention (CDC) (Figure 2). Interviews were conducted with over 30 persons including the incident manager, epidemiologists, clinicians, nurses, logisticians, community engagement experts, and laboratory specialists.

A list of pain points were identified, revealing several main themes: 1) delayed results – this impacted triaging patients in holding centers which affected patient safety and early treatment, propagated nosocomial transmission, and kept EVD patients in the ETU's longer than necessary after recovery resulting in valuable bed space being occupied unnecessarily; 2) lack of information systems – there was no process for data (patient result, epidemiological, operational) to be consolidated and managed; 3) inefficient communication – there was no process in place to ensure results were given to the correct person/team at the correct time for correct action and insufficient communication between teams; 4) lack of human resources and capacity – there were not enough trained staff to carry out necessary functions. Once the pain points were identified and mapped, all pillars within the incident management structure convened and system-wide solutions were ideated, developed, and implemented (Table 1).

Prior to conducting the process mapping exercise, it took on average six days for laboratory results to reach the intended audience. After partial implementation of changes, it took an average of 24 hours. The impact of the exercise was far reaching with an improved turnaround time and turn-over of patients in the ETUs and HCs. Better communication between all pillars within the IMS resulted in the improvement of critical services such as quarantined homes receiving food faster and better communication with families so they knew where their loved ones were. This improved overall engagement with the response and helped reduce distrust of the response. Additionally, the MoH was able to report on the number of confirmed cases with greater accuracy and timeliness to the public, partners, and donors. Furthermore, operational analyses could be performed to drive operational planning, including identification of hotspots and implementation of targeted risk communications.

CASE STUDY 2: YELLOW FEVER IN THE DEMOCRATIC REPUBLIC OF CONGO

A large multi-country yellow fever outbreak began in Angola in late December 2015 and soon spread to neighboring Democratic Republic of the Congo in March 2016. (49) Yellow fever (YF) is an acute viral hemorrhagic disease transmitted by mosquitoes. (50) DRC has a weak health system with an estimated 70% of the population having little or no access to health care. (51) It is a large, populated country with 81 million residing in 26 provinces that span 2.3 million square kilometers. (52) From 22 March through 20 July 2016, 1,907 suspected cases, 68 confirmed cases, and 95 deaths were reported in DRC alone. (49) The last confirmed non-sylvatic case had symptom onset on 12 July. (50) Although cases of yellow fever are regularly reported in DRC, (53) yellow fever outbreaks in high density areas are unusual, therefore the cases of YF in an urban setting necessitated a different response strategy to that of a rural outbreak.

A process mapping exercise was conducted in Kinshasa, DRC to address the challenges related to the flow of information from the community to the national MoH level (Figure 3). The exercise ran over the course of one week in late June/early July 2016, four months after the first case was confirmed. At the time of the process mapping exercise, there was a backlog of data across several districts in DRC and little confidence surrounding the numbers of suspected and confirmed cases. Delays in testing and limited epidemiological data posed challenges as it was difficult to assess whether the current response strategy was adequate. Thus, the national IMS was unable to understand the full extent of the outbreak and unable to make key decisions regarding important response factors such as where health staff should be located, planning and implementation of the vaccination campaign, and surveillance and laboratory activities. The process mapping exercise was conducted with MoH officials with support from the WHO and Institut National de Recherche Biomédical (INRB). Interviews were conducted with over 20 incident managers, epidemiologists, data managers, data scientists, and laboratory specialists.

A few key themes in the pain points were identified: 1) lack of standardized processes and procedures –case investigation and laboratory forms were often missing, inaccurate, or incomplete further affecting data accuracy; 2) lack of information sharing – there was insufficient collaboration and data sharing between key members working on the outbreak; 3) lack of human resources - there was insufficient staffing to manage the movement of samples and data and no designated data entry person, resulting in delays in updating and cleaning the data; 4) sub-optimal information systems – comparisons between the national level surveillance database and national level laboratory database revealed a discrepancy of more than 280 patient records and a backlog of over 90 paper case investigation forms that had yet to be entered into the database. The data were not archived regularly and were located on an individual staff member's computer. Other peripheral challenges mentioned included the sample storage and shipment and there was a lack of standardized yellow fever case definitions making it difficult to classify suspected, probable, and confirmed cases. Following the identification of the pain points, a variety of solutions were proposed with the implementation focused on the development of processes and procedures and associated data management solutions (Table 1).

Prior to conducting the process mapping exercise, it took on average 7 days to be notified of a suspected case of yellow fever. After partial implementation, this was reduced to an average of 3 days. The recommended actions improved the daily flow of data, allowing the national IMS structure to obtain a clear picture of the epidemiological situation which is required for decision making. It also catalyzed: a review of the placement of the mobile laboratories, the mapping of cases to understand movement of the outbreak, and the use of modelling to better plan the distribution of the yellow fever vaccination to the areas that needed it the most. Furthermore, the review and adaptation of the yellow fever case definition, followed by the training of health workers, significantly improved case detection and reporting.

CASE STUDY 3: MONKEYPOX IN NIGERIA

In September 2017, Nigeria experienced its first monkeypox outbreak since 1978.(54,55) Prior to this outbreak, monkeypox was not a priority disease in Nigeria with little or no awareness of the disease among health workers and no surveillance system in place. Monkeypox is a rare viral zoonotic disease with the average case fatality rate up to 11%. (56) At the time of the outbreak, there was no approved treatment or vaccine available, although prior smallpox vaccination is found to be highly effective at preventing infection. The disease is spread primarily through an animal reservoir, although human to human transmission has been documented. (57) Nigeria is a large, densely populated country with a de-centralized health system, giving each state significant autonomy in managing public health activities. (58) Additionally, over half of the population lives below the poverty line on less than one dollar a day, with only 43% of the population having access to healthcare.(59) This poses serious challenges in coordinating a multi-state outbreak. The outbreak resulted in sporadic cases over the course of the next year with a total of 122 confirmed or probable cases being identified and 7 deaths as of September 15, 2018.(60)

The mapping exercise was conducted over the course of one day in Abuja, the capital of Nigeria, two days after the monkeypox outbreak was confirmed. The objective of this exercise was to understand the total number of suspected and confirmed cases, their geographical location, and the associated operational challenges, in order to assess the extent of the outbreak and to inform resource allocation efforts. At the time of the mapping, cases were confirmed in one state with suspected cases in six other states, resulting in a potential wide geographic spread.(58) The mapping exercise was conducted in parallel to the national IMS structure being established, technical guidance documents and standard operating procedures (SOPs) being written and laboratory capacity being established.[23] The process mapping exercise was conducted by Nigeria's Centres for Disease Control (NCDC) with support from the WHO. Interviews were conducted with over 15 incident managers, medical officers, epidemiologists, data managers, and laboratory specialists. (Figure 4)

The primary pain points themes that emerged included 1) information management system challenges – incomplete information from case investigation forms (CIFs) resulted in limited understanding of the total number and location of suspected cases, 2) data collection challenges - incomplete investigations and collection of samples by surveillance officers which limited IMS' understanding of the situation in each of the states, and 3) communication of information. Other peripheral challenges were mentioned, such as insufficient number of isolation areas in the hospitals, sample storage issues - some samples were not properly stored impeding the laboratories analysis, limited personal protective equipment for clinicians, and lack of staff to conduct investigations and contact tracing. After the pain points were discussed and agreed upon, a list of solutions was ideated and implemented. These solutions focused on improving the level of engagement between the national level and states, training staff, establishing guidance and standard operating procedures for the IMS and surveillance teams, and detailing responsibilities and timelines for all personnel working on the outbreak (Table 1).

Prior to conducting the process mapping exercise, it took an average of five days to receive the CIF and case pictures at the NCDC National level. After the implementation of changes, it took an average of 48 hours. Furthermore, there was only a 24-hour delay in consolidating the data resulting in timely reporting of the suspected and confirmed cases to the incident manager. These changes enabled the IMS to make faster decisions regarding the allocation of resources to the affected states and allowed for timely reporting of case counts which could be shared with the public. Additionally, the new, timely information supported the development of associated risk communication, faster contact tracing to limit the spread of disease, and more effective deployment of personal protective equipment to affected districts.

LESSONS LEARNED:

My findings demonstrate the importance of utilizing process mapping during disease outbreaks as a tool to aid in the response while strengthening components of an already existing health system. This may be a particularly useful methodology to deploy during the current COVID-19 pandemic when there are many operational challenges and complexities. This is a methodology that epidemiologists, logisticians, community engagement experts, clinicians, infection prevention and control experts, laboratory specialists, and incident managers could familiarize themselves with as they are often the first individuals to work within the response system.

Process mapping should be considered at any phase of outbreak response to assess system-wide challenges and provide on-going monitoring of system improvements. They may also be done during IHR preparedness and readiness efforts and during post-event after-actions reviews. All three outbreaks occurred in Sub-Saharan Africa which may limit generalizability of results. Process mapping exercises have been done across numerous industries and settings around the world (33,37–41,61,62) and I therefore believe this methodology could be applied to outbreaks in varied geographic settings in low, middle, and high income countries alike. I encourage others to implement process mapping exercises during outbreak response to strengthen the generalizability and evidence base for this methodology. Further, the length of time from the start of outbreak to the initiation of the mapping exercise varied and therefore the I believe it is a useful methodology that can be deployed at any time point during any outbreak to assist in solving complex operational challenges. Additional research should be done to evaluate how the timing of the process mapping exercise impacts the processes. However, from my experience, the earlier the process mapping is conducted the less challenging the re-design will be considering there are fewer complexities and interactions that need to be addressed. This exercise was done to strengthen the flow of information and data associated with surveillance, clinical, and laboratory systems. I recommend utilizing process mapping in other contexts within an outbreak to improve generalizability to other areas of a health system.

The primary challenges in implementing this methodology during an outbreak included: 1) obtaining time from stakeholders to conduct the interviews and re-design session, 2) allocating human and financial resources to re-design the processes, and 3) changing priorities and epidemiological situation. Based on these challenges, I found an added level of situational awareness, openness, and flexibility is required by the persons conducting the exercise as well as those involved in the re-design as time is limited and the situation is evolving rapidly. Ensuring buy-in from leadership and strong stakeholder and partner engagement from the beginning was crucial as it allowed for human and financial resource support during the implementation of solutions. This also promoted accountability of stakeholders and partners during the implementation of the solutions. Keeping the interview time to under one hour per person reduced pressures associated with timing. During the re-design process I also highlighted the importance of a growth mindset which allowed for innovative approaches to be discussed and implemented. Designating one person to monitor the process through the outbreak and beyond will also support the sustainability of the re-designed process.

CONCLUSION:

The three outbreaks described had unique challenges and varying levels of complexity, including the size (number and geographic dispersion), duration (the length of the outbreak prior to the mapping exercise being conducted), and the existence of functioning systems. They also had many similarities. All outbreaks had challenges associated with the flow of data and information systems which impacted operational and strategic decision making required to rapidly guide the responses. A common challenge across all scenarios was ensuring sufficient and trained staff had clear responsibilities, timelines, and built-in accountability mechanisms. Each scenario also necessitated improving the working relationship and strengthening communication and coordination between the laboratory, clinical, and surveillance teams. All three countries had already existing systems that managed data and flow of information prior to the outbreak. However, all of the systems were overwhelmed once the number of suspected cases increased. The impact on the process mapping exercise in all three countries was witnessed within days: communication between stakeholders was enhanced, strategic decisions were made possible with good data, and ancillary and supportive health system services improved. I aimed to re-design resilient processes that evolves as the situation allows and therefore the process mapping exercise should be reassessed and repeated as necessary to allow for further system refinement. A challenge associated with this is ensuring sufficient resources to monitor, re-evaluate, and re-adjust the processes over time and I suggest that this is built into the mapping exercise during the planning stage. The re-evaluation and re-adjustment concepts are key activities required for long-term health system strengthening and I believe long-term positive changes will be noticed as has been demonstrated through process mapping exercises in other disciplines (33,37–39,41,42,61–63)

The solutions created were often simple yet had tremendous impact. Moreover, financial requirements were minimal and consisted of only staff time. If large scale improvements are required such as development or improvement of data systems and interconnectivity, financial requirements may be high. While the full implementation of the re-design can have financial costs; as demonstrated, there are innovative ways to address process related issues that are no-to-low cost such as improving communication between teams, establishing clear roles, using organizational tools such as stamp pads, responsibilities and timelines, ensuring all persons and teams understand their own purpose and roles along with those whom they should be working closely with, and writing SOPs and ensuring everyone is adequately trained on them.

Chapter 4: Creative Problem-Solving Methodologies

A. Design thinking methodology

BACKGROUND:

The availability of timely and accurate data during a disease outbreak is critical to decision making yet challenging to obtain, as can be seeing in the COVID-19 outbreak and other acute public health events. During the 2014 Ebola outbreak in Liberia, Sierra Leone, and Guinea in West Africa, similar challenges were faced with the identification of cases, collection, management, and reporting of data. (64–66) As a rapid and effective response requires the use of data to make operational and strategic decisions, the lack of regular and accurate data limited the understanding of the outbreak, including transmission dynamics and impacted overall operations, planning and allocation of resources, and support from the international community at large. (66) At the end of the outbreak, more than 250,000 samples were tested in 47 laboratories deployed in the 3 countries and there were an estimated 28,616 suspected, probable, and confirmed cases and 11,310 deaths.(67)

The multi-faceted challenges and needs associated with identifying, collecting, managing, analyzing, and reporting data in an infectious disease outbreak lends itself to applying innovative techniques and methodologies during the responses. (68) Design thinking is a process for creative problem solving and allows ill-defined or challenging problems to be reframed in a human-centric way which focuses on the end-user and allows teams to develop practical and innovative solutions for problems. (69–72) Design thinking as a concept dates to the late 1950s in the design engineering and science fields, with one of the first models created by Herbert Simon in 1969. (69) There are different variations of the design thinking process ranging from three to seven steps; although, all are based on Simon's model (32,69,72) Over the last few decades, the methodology has been used in numerous fields including business, education, computer science, healthcare and public health management and policy can address a wide range of problems. (69–71) In the 1970's, Victor Papanek, a pioneer in design thinking, collaborated with WHO experts to create a low-tech malnutrition arm band for children. (69,73) More recently, human centered design and design thinking was used to integrate tuberculosis and human immunodeficiency virus care in Kenya, (74,75) for asthma self-management in Scotland, (74,76) for dementia patients in the UK, (74,77) and for designing a backpack for school-aged children in Iran. (74,78) It was so also used to design a surveillance and outbreak response management system for Nigeria post-Ebola outbreak. (74,79)

To address the challenges associated with collecting and reporting data during the 2014 Ebola outbreak in Guinea, Liberia and Sierra Leone, I applied a design thinking approach to build the Global Ebola Laboratory Data Collection and Reporting System. (66) I aim to demonstrate how design thinking can be used during complex emerging pathogen outbreaks to solve acute and long-term challenges within the health information system.

DESIGN THINKING METHODOLOGY:

In building the data collection and reporting system, (66) I used the five-stage Design Thinking model proposed by Hasso-Plattner Institute of Design at Stanford University. (72,80) Prior to implementing the design thinking methodology, I also assessed the potential usefulness of the Cynefin Framework and the Eight Disciplines Problem Solving Process (8D) to understand which methodology would be most effective and efficient in an outbreak setting to design the data collection and reporting system (81,82). Design thinking was chosen as it has documented use-cases in healthcare and public health, supports rapid prototyping, is non-linear has a low-cost of implementation and has a low barrier to entry requiring minimal training. Additionally, it is a collaborative methodology, which is particularly important during outbreaks and health emergencies when health systems are being pushed to their limits. This approach offers a flexible model which focuses on empathizing, defining, ideating, prototyping, and testing. Engaging end-users throughout the design thinking process is paramount to ensuring that solutions are developed to meet user needs. This is an iterative methodology that continues to adapt according to the needs of the system. Therefore, many of the stages do not need to be sequential and can be run in parallel, out of order and repeated as necessary. (32,72)

Empathizing

The design thinking process began simultaneously in Guinea, Liberia and Sierra Leone with observing, engaging, and empathizing with the current situation. This step allows for the removal of personal assumptions with a view of observing the problem through the end-user's perspective. (31,72) To do this, I met with senior leadership within the Ministries of Health and incident managers to understand the challenges as it relates to obtaining accurate and timely information and to obtain a landscape of all players whom would need to be involved. I then reviewed daily situation reports (a document which details the number of confirmed, suspected and probable cases and deaths, and highlights the operational challenges). Next, I worked in the three countries alongside end-users and stakeholders who were collecting and analyzing the data as well as using the reports for decision making. Multiple one-on-one interviews and small workshops were carried out in Sierra Leone, Liberia and Guinea in-person and remotely via teleconference. Through these meetings, I was able to gain situational awareness and understand the unique needs that each stakeholder had in relation to the data collection, management, reporting and decision making. Questions focused on understanding the current workflow, identifying bottlenecks, and the diverse end-user roles and responsibilities that the data collection and reporting system needed to support. Additional questions focused on understanding the short-term and long-term needs of the data. This information was written up after each interview and workshop and compiled into a central excel document for later review and prioritization. The key end-users and stakeholders were data collection officers, epidemiologists, information technology staff, data managers, laboratory personnel, technical experts, and senior leadership from the Sierra Leone, Liberia, and Guinea Ministries of Health.

Defining & Ideating

Next, the end-user and stakeholder needs were defined and the problems were clearly identified and articulated (Figure 5). Through multiple brainstorming sessions, ideas were generated to address the list of needs and challenges of the end users and stakeholders. As the list of needs and challenges was generated independent of the persons rank and title within the organizations, it was possible to objectively and equitably ensure all persons had a voice in this process. The ideas focused on features, functions and design characteristics essential to improving the data collection and reporting process and ranged from simple adjustments to the creation of complex systems. Prioritization of the ideas was based on speed, feasibility and flexibility due to the time constraints necessary to develop and roll-out the system.

Prototyping

With the information obtained during the empathizing, defining, and ideating stages, it was possible to view the problem from alternative ways and to design new and appropriate solutions. During the prototyping phase, I worked closely with IT system engineers and computer programmers to design a solution that would fit the needs of the various end-users and stakeholders according to the required list of features and functions. The list of features included searchability, standardization of data, real-time access to data, data management including cleaning and validation capabilities, and visualization of data. The list of system capabilities included data ownership and access, security, off-line use, usability with limited internet connection, versatility of languages, flexibility and adaptability to various types of users.

Testing and Re-Design

A prototype of the data collection and reporting system was developed over the course of two months. During prototyping, the focus was on identifying the best possible solutions to address the problems and requirements identified in the earlier phases. (32,72) Lastly, the system was tested internally by the IT team and subsequently rolled-out to Guinea, Liberia and Sierra Leone. Once the system was implemented, the team had regular weekly calls to discuss operational challenges and to make necessary adjustments based on the specific needs of each country. This was an iterative process with alterations and refinements being made to the system after receiving valuable feedback from end-users. (32,72) The system took nearly 1.5 years of iterations until it was maximized to its full potential. (Figure 6)

RESULTS:

From March 2014 through August 2016, the results of 256,343 specimens tested for EVD in 47 laboratories across Guinea, Liberia and Sierra Leone were captured in the Global Ebola Laboratory database. (66) The value of the database was far reaching. It was used to orient the response at the district, national, and international levels within the three countries including generating situation reports, monitoring the epidemiological and operational situation, and providing forecasts of the epidemic. (66) It was also used to support additional Ebola-related public health interventions including the Ebola RNA persistence in semen of Ebola virus disease survivors report (83) and the Ebola National Survivors programs within each country. Further, the platform in which the Ebola data collection and reporting system was built on was adapted through end-user feedback, testing, and IT upgrades to support the 2016 yellow fever outbreak in Democratic Republic of Congo and Angola.

DISCUSSION:

Using a design thinking methodology during an outbreak allowed for buy-in and end-user expertise to drive the initial design of the system; which allowed for implementation during an outbreak. As requirements were defined by end-users for all stages of the data collection, management, analysis, and reporting phases, the first prototype that was rolled-out was immediately useable by end-users and subsequent modifications were enhancements instead of re-designs. Further, as there was buy-in from end-users, stakeholders, and leadership, it was feasible to roll-out the system simultaneously in all three countries. With active end-user feedback, it was possible to make small incremental changes over time which upgraded the system to enhance usability without impacting functionality. Small incremental changes were used instead of large system overhauls in order to not impact daily entering and reporting of the data and to minimize the amount of ancillary training that was required. Further, the on-going engagement required from the design thinking methodology resulted in strengthened communication and collaboration between and within end-users and stakeholders for harmonized strategic interventions.

Limitations of the design thinking approach for this context were threefold. Firstly, co-creating a solution with end users required sufficient contribution of their time and participation in the design process. I recommend that teams looking to implement design thinking during a public health emergency remain cognizant of this and find agile ways of working to accommodate for valuable time that must be spent on critical response operations. A second limitation is that the focus on user centricity, especially when working “bottom-up” to create a solution, may favor certain user personas over others in the solution design. To accommodate for this, I worked iteratively to gather feedback from users at the country, regional, and global levels and to align needs when developing the data system design roadmap. I also recommend the use of project management methods alongside design thinking to manage the scope, timing, and release of data system enhancements. Lastly, critiques of design thinking in the literature note that unlike other design approaches, design thinking is poorly defined, less grounded in theory, and may narrow the potential for innovation. While, the flexibility of this methodology was advantageous during this outbreak, it may not be as useful for other settings.

Cori, et al. outlined three components they found necessary in order to have useable data for analysis and decision making: 1) collecting relevant data, 2) optimizing data quality, and 3) data availability. (84) Based on challenges described in this manuscript along with Durski, et al. *Development, Use, and Impact of a Global Laboratory Database During the 2014 Ebola Outbreak in West Africa*, (66) I agree with the recommendation from Cori, et al. and encourage this framework for future data system development.

Further, in order to use design thinking to strengthen health information systems and to increase the likelihood of the output being adopted, I identified five conditions that should also be present:

i) Leadership should be involved from the beginning and have the interest and capacity to allocate resources and time accordingly. The senior leadership within the Ministry of Health and Incident Command Structure in Guinea, Liberia and Sierra Leone all supported the development of a data collection and reporting system and allocated staff accordingly to work with us in the development of the system,

ii) There needs to be an environment in which change is required. This was evident by the acute challenges associated with the outbreak and the need for and lack of timely and accurate data to inform decisions,

iii) Strong engagement with end-users and all stakeholders is necessary. Even though there were over 60 stakeholders across three countries in multiple languages, following design thinking principles allowed for a wide-range of requirements from data collectors to analysts to decision makers to be collected, analyzed, and incorporated into the final system,

iv) Strong coordination and facilitation are important. Ensuring that all stakeholders and end-users contributed to all phases ensures short-term and long-term buy-in of the system.

v) Designing and developing a system which is multi-purpose and addresses complex challenges requires everyone involved in the process to be flexible and have a growth mindset.

The inherently chaotic nature of an outbreak poses a unique set of limitations when implementing response strategies and operational research. As a result of the time pressures, the meetings with stakeholders and end-users were conducted in an ad-hoc manner by country instead of in a large, collaborative group setting by bringing together stakeholders across the region. Additionally, this was complicated due to the French and English language requirements and poor flight and transportation connectivity between Guinea, Liberia and Sierra Leone at this time of the outbreak. Additional experts in design, user experience, and data science fields could have been included in the design thinking phase. While I attempted to include these specialties, it was not possible due to the tight timelines of the outbreak and limited resources allocated to the creation of the data collection and reporting system. These experts could have provided unique and complementary perspectives during the design phase when working side by side with end-users.

Despite numerous challenges, the design thinking methodology was paramount in developing a data collection and reporting system during one of the most complicated outbreaks to date. (66) I suggest the continued testing and use of design thinking to solve health system related challenges that arise during disease outbreaks and health emergencies. Due to the varying complexities and challenges associated with COVID-19 outbreak and other acute public health events, I suggest the use of design thinking as a key methodology to address health system challenges, particularly those which rely heavily on end-users to be successful and sustainable.

B. Data Collection and Reporting System

BACKGROUND

The 2014 Ebola outbreak in West Africa was declared an international public health emergency in August 2014. (85) The high degree of population mobility across porous borders in West Africa introduced operational challenges and contributed to the rapid spread of EVD. (86) The regional and international impact of EVD demonstrated the importance of centrally compiling data in order to understand disease trends and guide public health interventions.

The effectiveness and efficiency of a public health response during an outbreak is dependent on having reliable and up-to-date information as the outbreak evolves. (87,88) Lessons learned from past communicable disease outbreaks have emphasized the importance of having an accurate and real time database that is accessible to relevant agencies involved in the outbreak response. (3,89) Information from laboratories is particularly invaluable for outbreak control activities. (90–92) During the early stages of the 2014 Ebola outbreak, the laboratory and surveillance systems were not linked and reporting of daily laboratory results provided the most reliable and timely information in comparison to delayed epidemiological reporting due to overwhelmed surveillance systems. Guidelines for laboratory data management, as part of the laboratory capacity requirements for IHR 2005, recommend computerized laboratory information systems, standardized data collection, and periodically disseminated activity reports at each level of health care service delivery. (93,94)

The WHO Emerging and Dangerous Pathogens Laboratory Network (EDPLN) is a network of high security diagnostic laboratories that contribute to long-term outbreak preparedness and response efforts. (95) Established in 2008, the WHO EDPLN with the support of Global Outbreak Alert and Response Network (GOARN) has overseen the global deployment of mobile field laboratories during outbreaks. (96) For the 2014 EVD outbreak, laboratories were deployed in the three most affected countries (Guinea, Liberia, and Sierra Leone).

To address the gap of a consolidated, centralized laboratory database which is necessary to inform response in a multi-country outbreak, EDPLN supported the development, maintenance and implementation of a global laboratory database. The database collated and reported data in near real-time from 47 laboratories in Guinea, Liberia, and Sierra Leone. In contrast to other web-based data systems, it is a spreadsheet-based system, which allows for maximum adaptability, IT literacy, and coordination between data collection and collation. This paper outlines the methodology, practical applications, and limitations of the global laboratory database used to respond to the recent EVD outbreak.

METHODS

Laboratory Diagnostic Capabilities

Through EDPLN and bilateral agreements with the EVD affected countries, fixed and mobile laboratories were deployed to support diagnosis and confirmation of suspect and probable cases of Ebola as well as the discharge decisions of convalescent Ebola patients. The laboratories were owned and deployed by Belgium, Canada, China, England, France, Germany, Italy, Netherlands, Nigeria, Senegal, South Africa and USA. Some countries deployed multiples laboratories throughout the region (Figure 7).

Specimen Collection

Specimens were collected from patients presenting at hospitals, treatment centers, and clinics who had symptoms concordant with respective MoH and WHO case definitions for EVD. (97,98) Patients who tested negative for EVD with less than 48 hours between symptom onset and specimen collection were re-tested. Successive specimens were collected from EVD positive patients until the patient received two negative test results at which point they could be discharged. Oral swabs were also collected from dead bodies in the communities and health facilities according to protocols. (99) All specimens were transported to the laboratories for subsequent real-time qualitative Reverse Transcriptase Polymerase Chain Reaction (qRT-PCR) testing.

Data Collection

At the start of the outbreak, laboratory staff collected ad-hoc demographic data from the Case Investigation Forms (CIF) and entered it into an excel spreadsheet alongside laboratory results. In early 2015, all mobile and fixed labs that were members of EDPLN and/or were established *de novo* based on bilateral agreements between donor countries and the three West African countries implemented nationally standardized spreadsheets for data collection.

Nationally standardized spreadsheets were developed using Microsoft Excel 2010 and compatible versions by key stakeholders within Guinea, Liberia, and Sierra Leone, in collaboration with the WHO. Microsoft Excel was chosen over tablet computers, smart phone-based applications, and web-based platforms as it required relatively low computer literacy, inexpensive software investment, and could be used in areas with limited internet connection. Each country's MoH devised their own processes and procedures related to reporting requirements from the laboratories including identifying which data fields were required for reporting. At a minimum, results were emailed once daily from the laboratory to the MoH, in addition to the relevant clinical teams.

Laboratory Results Consolidation

Results consolidation occurred at the national and global levels, with the processes being strengthened and standardized as the outbreak progressed. National database managers or focal points were responsible for consolidating data for in-country use and electronically sending to WHO. Each spreadsheet from the country was imported into a database using extract, transform, and load (ETL) tooling. Data loading packages migrated data from spreadsheets with structural and contextual variations into a consolidated database. Data standardization was incorporated into the loading process by automatically formatting a series of expected inputs to standard outputs. Fields such as sex, age, test sequence and dates were standardized in this way. Entries that did not match the expected list were manually reviewed prior to loading as part of a data verification process.

Record Verification and Cleaning

Record verification and cleaning was conducted during three stages of the data management process to minimize and rectify manual and electronic errors that may have occurred during data collection and data loading. Prior to loading the data, fields were formatted to ensure successful importation into the database. Once uploaded, records were manually reviewed and reference tables were updated according to standard operating procedures (SOPs) to provide further data standardization and quality assurance. All staff involved in data management and cleaning were trained on implementing SOPs in order to ensure consistency in all data cleaning and verification processes. The last stage of verification occurred while conducting analyses to confirm accurate representation of the situation in-country. Gaps in information were resolved through regular communication and validation with MoHs, WHO country offices, and laboratories.

Data Analysis and Reporting

The database was linked directly to a secure web-based dashboard where aggregate numbers, graphs, and charts were accessed in real-time. Descriptive and statistical analyses were conducted with STATA13 (StataCorp, College Station, Texas, USA) and Microsoft Excel (Washington, USA). Analyses were compiled into weekly reports and disseminated to MoHs, laboratories participating in the response, and other partners as guided by the respective MoHs. Data were analyzed to identify local and regional trends as well as to assess and adapt operational response strategies.

Data Ownership, Access and Security

Ownership of the laboratory data remained with the respective MoHs. The system utilized a three-tier data access system which enabled national, regional, and global stakeholders to directly export consolidated and cleaned data from a web-based platform according to their pre-designated access rights. Access to the data and reporting dashboard was granted via unique, secure usernames and passwords under the clearance and guidance of the respective MoH.

System Design

The laboratory database was designed to easily adapt to any infectious disease outbreak and with in-country end-users in mind. To account for the unpredictability of outbreaks, data loading packages were built to accommodate varying levels of data quality from a variety of data fields. Data loading, management, and analyses relied on Microsoft Excel in order to improve flexibility in data processes and to reduce the need for computer programmers. Functions to maintain data integrity while improving quality were included to ensure records could be updated as necessary and changes could be traced back to the persons working within the dataset. The database was also archived daily to allow for recovery of information if and when needed. Figure 8 depicts the data flow process from specimen collection to reporting and analysis.

RESULTS

The first set of laboratory results were received in March 2014. As of 31 August 2016, the database consisted of 256,343 specimens from 4,830 spreadsheets reported from 47 laboratories located in Sierra Leone, Guinea and Liberia. On average the data was analyzable within 24 hours from receiving the test result. The database captured 39 different types of specimens tested in these laboratories for EVD, the majority of which were blood specimens (38%) and oral swabs from dead bodies (41%). The remaining specimens tested include environmental swabs, maternal blood, capillary blood, breast milk, semen, and other bodily fluids. Non-EVD tests such as malaria, blood biochemistry, and antibody tests performed concurrently to EVD testing were included in the database, although these accounted for less than 5% of records.

With regards to data quality, analysis of data completeness showed variations by data field (1.3% to 100%) across the three countries (Table 2). Approximately half of the data fields within the database had greater than 75% data completeness, although each country prioritized certain data fields in order to account for country specific needs.

Data completeness also varied over time. From August 2014 (testing week 31, 2014) through November 2014 (testing week 48, 2014), laboratory testing across the three countries increased at a rate of 11.7% per week. During this period, data completeness of key fields remained between 75% -85%, after adjustment for country variations. By January 2015, data completeness rose to 89%, and fluctuated between 89%-96% data completeness through 2016 despite relatively sustained high levels of laboratory testing (Figure 9). This increase may be attributable to a decrease in the percentage of positive samples as well as efforts by the WHO teams to implement standardized spreadsheets, provide regular feedback, training, monitoring, and support to improve data quality and data collection.

The broad range of data fields collected allowed for a multitude of analyses, which could be refined over the course of the outbreak as well as post-outbreak. The lab data provided information necessary for monitoring, forecasting, supporting research questions, and providing epidemiological and strategic direction. Analyses from the database focused on but were not limited to understanding laboratory capacities, monitoring the functionality of the laboratory and response systems, understanding key demographic data of the patient population, mapping the geographic distributions of positive specimens, and illustrating the burden on clinical services and community burial teams (Figure 10).

DISCUSSION

The geographic spread of cases, volume of laboratory tests performed, and speed at which information needed to be compiled to inform outbreak activities demanded an effective laboratory information system from the start of the 2014 EVD outbreak. Characteristics of ideal data systems include those which are electronic, (100) automated, (100) free from political bias, (89) and respectful of country sovereignty. (91) The laboratory database described in this paper provided valuable and near real-time data that was utilized for quick decision making at various levels of the outbreak response, particularly when the epidemiological and surveillance systems were overwhelmed. The key lessons learned in the creation of a global laboratory database primarily pertain to the need to strengthen integrated data systems, to ensure standardized data collection tools and processes are in place, to invest in dedicated data management and IT teams, and to maintain regular communication, feedback and collaboration.

The utility of a database is predominately dependent on the quality of the data received. In resource limited settings, laboratory staff may collect and manage case information through log books, paper records, and other non-standardized paper methods. (92,101) While these approaches provide a quick and convenient method to compiling information during small-scale disease outbreaks, the large number of cases in the 2014 EVD outbreak required a consolidated, electronic database that could provide real-time results across multiple locations. However, there were numerous challenges associated with the timely collection and reporting of data when existing data systems were overwhelmed. In the beginning of the outbreak, reported data varied considerably by laboratory and country as did data quality. For example, data was reported on an ad-hoc basis, dates were entered in both American and European standards, colloquial location names were used instead of officially recognized names, and open text fields introduced variation that made interpretation difficult (e.g. the comments field contained additional information on specimens, clinical presentations, etc.). Utilizing standardized spreadsheets with dropdown menus and locked formatting reduced data entry errors and improved data integrity. I recommend prioritizing the strengthening of data systems during preparedness and recovery efforts to ensure data usability and the connectedness between systems. In the event a laboratory system does not currently exist, deploying and implementing a standardized data collection and management package at the start of an outbreak to each of the reporting sites and/or laboratories should be considered. Efforts should also be made to ensure all laboratories are uniformly entering the data and that protocols and procedures for data flow are established.

Previously documented laboratory data systems have attributed data quality challenges to limited computer literacy (91) and internet availability. (101) However an additional challenge in the 2014 Ebola outbreak was ensuring consistent and error-free data during high staff turn-over and utilization of multiple data collectors or data entry specialists. For example, District Surveillance Officers and Epidemiologists filled out paper-based CIFs, which detailed demographic data and unique patient identifiers. Laboratory technicians and data clerks, many of whom were on four to six-week rotations, re-entered the CIF data into along with the laboratory results after the diagnostic EVD tests were completed. Often the format of the laboratory spreadsheet changed with lab staff turnover and in-country needs and decisions. Without adequate human resource support and open communication, even the most efficient database processes, user-friendly data collection tools, and the most robust analyses will fall short. I recommend long-term investment into data management teams at the national level in order to ensure accurate and consistent data collection, management, and reporting. Further, developing a human resource plan for a data management team to ensure sufficient knowledge transfer in the event of staff turn-over, designation of focal points with clear terms of reference, roles and responsibilities to address data related issues should be considered. Ensuring daily communication and feedback between all laboratory and data clerks/data managers is essential.

In order for a laboratory data management system to be useful in emergency situations, it must have mechanisms to adapt quickly, for changes to be reflected immediately, and for data to be deleted and modified without having to alter the entire system. (91) The size of the global laboratory database, variability of information collected and entered, sensitivity of the data, and need for reliable and up-to-date information demanded significant dedicated on-site IT resources to immediately implement system changes based on in-country needs. I suggest planning and budgeting for long-term IT support when developing databases to ensure efficiency, sustainability, and functionality over time.

A limitation of the global laboratory database is that records are at the specimen level instead of the patient level. Retrospectively linking data to the patient level and subsequently to other data sources, such as burial, clinical, and surveillance data, was not done during the outbreak and will require additional time and human resources. Developing and implementing a unique patient identification (ID) system at the beginning of an outbreak, actively maintaining the ID system throughout the outbreak, and developing a single database with complete laboratory, clinical, geographic, and epidemiologic data of all suspect cases, contacts, and survivors is critical to ensuring useable data at both the patient and specimen level. An additional limitation is that despite the best efforts to verify and clean data, there may be inaccurate records (e.g. date of specimen collection is after date of test) in the global laboratory database if data collectors and data clerks are no longer contactable or in the case that paper-based records are no longer available.

The utility and value of the laboratory database has been far reaching. With substantial amounts of data being shared and integrated on a common platform, the system was able to inform global response strategies and prompt decision-making as well as address research questions that were not considered during the height of the 2014 EVD outbreak. The multi-functional global laboratory database can be easily adapted to any type of infectious disease outbreak and is quickly deployable with minimal training required for end-users. Its utility for disease forecasting should be explored further. Additionally, the database has the potential to act as a virtual biobank, functioning as a digital repository where users can add, track, and share specimens. As demonstrated through the global laboratory database, it is possible to design, implement, manage, and analyze large amounts of data with multiple stakeholders and collaborators, different languages, various levels of user-access, multiple data flows into and out of countries, and with different end-user needs to inform immediate needs during outbreak response.

Chapter 5: Conclusion and Next Steps

Major Findings & Contribution to Science

As the COVID-19 pandemic has demonstrated, we have a long way to go to strengthen our health systems abilities to absorb the consequences of health emergencies. The traditional approach of prioritizing the strengthening of health systems during preparedness and recovery efforts should be shifted to also include prioritization (when possible) during the response phase. Using the crisis and the associated influx of funds as a launchpad to build better and responsive systems for the future is imperative.

There are challenges across every aspect of the health system in low, middle- and high-income countries alike and many unanswered questions related to how we most effectively address them during an outbreak. To date, there are a limited number of published articles which demonstrate how we can use disease outbreaks to build health systems resilience. My research shows that despite the complexities associated with responding to disease outbreaks and building health system resilience, numerous benefits emerge when implementing systems thinking and creative problem-solving methodologies. The disease outbreaks in which the systems thinking and problem-solving methodologies were implemented were very different; yet they proved to be valuable across all scenarios. As demonstrated, the implementation of these methodologies should be considered at any phase of an outbreak, regardless of resource constraints. Further, prioritizing methodologies which are end-user focused and collaborative allows for wider engagement in the problem and uptake of the solutions.

My research contributes to science in three ways. I, along with experts in the field of outbreak response and health systems strengthening advocated for a shift in perspective and change in modus operandi during outbreaks to ensure each outbreak is used as another opportunity to strengthen a health system. I identified a set of conditions that should be present at the national level in order to carry this out and highlighted 10 concrete activities that can be implemented.

The usefulness of implementing process mapping, a systems thinking methodology, during an outbreak to adjust the acute response but also contribute to components of health system strengthening efforts was proven to be successful. Along with colleagues in DRC, Nigeria, and Sierra Leone, I was able to demonstrate that it is possible to implement systems thinking during an outbreak in an ethical way without diverting critical resources. In Sierra Leone, laboratory testing accelerated from six days to within 24 hours. In Nigeria, key data reached the national level in 48 hours instead of five days. In the DRC, time to suspected case notification reduced from seven to three days. Further, as this was done in three countries, during three unique outbreaks, in three time-periods, there is greater generalizability of the methodology. This approach proved its usefulness in improving communication and collaboration among a diverse set of stakeholders and partners.

I was able to provide evidence that the creative problem-solving approach of design thinking can be implemented in an outbreak to improve the response and the health information system. Along with colleagues in Guinea, Liberia, and Sierra Leone, I demonstrated that design thinking was not only effective in developing a data collection and reporting system which could be used during and post-outbreak but that it is a useful methodology to enhance collaboration and communication between stakeholders and partners. The design thinking approach enabled the capture of data for 256,343 specimens being tested for EVD in 47 laboratories across Guinea, Liberia and Sierra Leone. The data collection and reporting system was used to orient the response interventions at the district, national, and international levels within the three countries including generating situation reports, monitoring the epidemiological and operational situations, providing forecasts of the epidemic, and supporting Ebola-related research and the Ebola National Survivors programs within each country. The multi-functional global laboratory database can also be used to create a virtual biobank, the data can be used for disease forecasting, and the data system can be adapted to other disease outbreaks.

Challenges and Lessons Learned

Through the course of advocating for a paradigm shift, challenges did arise. A detailed list of challenges and lessons learned for the process mapping and design thinking methodologies were outlined in Chapters 3 and 4. The additional challenges I encountered were primarily associated with people, politics and funding.

The disciplines of outbreak response and health system strengthening are well-established and the organizations and individuals which have operated in these domains are invested in the outcomes specific to their respective areas of work. Advocating for a shift in approach may cause them to feel as though their work is being attacked or discredited. Further, as both disciplines are comprised of experts who have technical experience in their specific domains, they may not have as much insight into the challenges of the other discipline and therefore may not see the need for a new approach. Creating opportunities for enhanced collaboration and co-creation of solutions which bridge both outbreak response and health systems strengthening may break down some of the barriers to prioritizing health system strengthening during outbreak response. For example, during the response this can be supported through establishing pillars within the Emergency Operations Center which are co-led by one person with expertise in the particular response operation along with a person who focuses on long-term strengthening of the associated system. That is, within the information management/surveillance pillar, one co-lead could be the head of disease surveillance unit while the second co-lead could be an expert working on the long-term strengthening of the national information management system. Further, at the beginning of each outbreak, the IMS could prioritize one or two response activities which are the result of a health system challenge and appoint a dedicated multi-disciplinary team to ensure this is strengthened. In addition, during preparedness activities, national and sub-national health authorities can be mindful of the participant make-up in order to build and strengthen relationships between the two disciplines and other important traditional and non-traditional partnerships. Networking events and research conferences can establish "themes" that pull from both disciplines in order to strengthen personal and professional relationships. Further, ensuring a broad make-up of participants in lessons learned exercises, including activities such as surveillance system evaluations, can also contribute to joint understanding of challenges and further break down silos between the two disciplines.

Politics and the prioritization of funding also have important implications which were evident in my research. The political landscape at the time of the outbreak, specifically during election years, impacts the public health response and associated shift of resources. With strong political support and interest in public health, it is possible to test and incorporate novel innovations and practices such as the methodologies tested.

Funding shortages across public health initiatives also creates unnecessary competition between the disciplines which disincentives an inclusive and innovative environment. Developing solutions which bridge both public health disciplines along with the broader economy can support the allocation of limited funding to both activities. Many of the challenges associated with politics and funding are systemic and therefore likely require long-term innovative solutions. For instance, national health authorities could develop unique collaborations with the private sector to develop a revolving fund which supports the strengthening of public health systems during health emergencies such as the CDC Foundation's Emergency Response Fund or the AMR Action Fund (102,103). Tax write-offs could be designed for Companies who opt-in to contribute a certain percentage of profits to a “systems strengthening during emergencies” fund. National health authorities could also develop their own sustainable and innovative funding mechanisms such as creating thematic social responsible exchange traded funds (ETFs) to supplement public health funding providing long-term relief to systemic public health funding shortages such as was done with Loncar Funds which supports cancer immunotherapy or Infrastructure Capital Advisors which has two ETFs that allow the firm to allocate 10% of its revenues to fund “Tutoring America” (104,105) Through these innovative types of funding sources, national and subnational health authorities could have the flexibility to prioritize the allocation of funds according to defined principles and criteria which support both disciplines. In addition, performing economic analysis and modelling to demonstrate the relative importance of interventions and the economic impact of the outbreak can prove valuable to gain public awareness as well as garner additional financial support.

Through reflection of the challenges I encountered throughout my research, I developed the below ten questions, named **"The 10 W's"** to serve as a guide for others who want to strengthen components of health systems during emergencies. The intention of this list of questions is to provide public health practitioners and/or researchers a broad framework prior to embarking on work that strengthens components of a health system during outbreak response.

i) Will this work have senior leadership buy-in and involvement with sufficient resources to carry this out?

ii) Will it be possible to have strong engagement with end-users and stakeholders at all levels of the response (From junior staff to senior leadership across both technical and political domains)?

iii) Will this have long-term institutional support and buy-in from governments and partners?

iv) Will this be in alignment with ***both*** outbreak response goals and health system strengthening activities?

v) Will this deter valuable resources (human and financial) away from the critical response operations?

vi) Will this have unethical, unintended consequences either for the acute response and/or long-term systems strengthening efforts?

vii) Will this be feasible to implement during an outbreak?

viii) Will the success of the response AND system strengthening efforts be measurable?

ix) Will this be sustainable (financially and human resources) beyond the immediate outbreak response efforts?

x) Will a by-product be enhanced communication and improved ways of working together for the involved teams?

Implications for Practice and Policy

There is a fine line between strengthening resilience systems while also ensuring their sustainability. Both resilient and sustainable systems are critical for population health and need to be prioritized during response efforts. Resilience is the capacity of a system to deal with change and continue to develop. (106) Sustainability is ensuring a process or state can be maintained at a certain level for as long as it is wanted. (107) While both are complementary, they are different, and we therefore need to be aware of this when conducting activities and developing policies to support the response in order to ensure that rigid and untenable systems and processes are not built.

Due to the dynamic environment of politics and the health workforce, leadership and staff changes impact the transfer of knowledge and sustainability of projects. During my research, senior leadership and staff at Ministries of Health and various partner organizations were strong advocates for the two methodologies tested and implemented; however, in time they will leave their organizations and with them the knowledge of the methodologies. Multiple strategies can be enacted to reduce the impact of this potential loss of information. As mentioned previously, at the policy level, a framework can be developed or re-aligned to ensure the systematic approach and implementation of methodologies to streamline response efforts while strengthening components of a health system. Additionally, at the workforce level, a toolkit which includes easy to implement methodologies for outbreak response specialists can be created and associated trainings conducted in all major epidemiology training programs such as Centers for Disease Control and Prevention Epidemic Intelligence Service program (EIS), National Field and Epidemiology Training Programs (FETP), the European Programme for Intervention Epidemiology Training Program (EPIET), and others. Over time, through continued inclusion and use of the methodologies, their implementation during outbreak response will become second nature, just as are the steps for conducting outbreak investigations or setting up emergency operations centers.

To further complement this, a high-level checklist could be developed for public health leaders and policy makers to ensure awareness of and support in the implementation of these methodologies and to provide guidance on how to leverage health emergencies to build better systems. This includes guidance on how to: align response activities with health system strengthening activities, target communication and advocacy efforts to partners and the general public to garner support for long-term systemic issues during the health emergency, develop the necessary associated policies which highlight the prioritization of and use of funding to strengthen system resilience during health emergencies, design policies which absorb an influx of funding for the acute and long-term systems strengthening activities, and advocate for dedicated budget lines for health systems strengthening activities during outbreak response.

Engaging donor agencies and traditional and non-traditional partners is also important. Providing dedicated funding that prioritizes activities that support both acute and long-term systems strengthening activities will allow for sustained support for long-term strengthening of systems which is required to improve public health. As witnessed through shifting priorities during the 2014 Ebola outbreak, the current COVID-19 pandemic, and other epidemics, the strength of donor agencies such as the Gates Foundation, United States Government, UK Medical Resource Council, and Wellcome Trust can have a significant impact on the policies and priorities of countries. In addition, the influence of the private sector should be harnessed when health system challenges are identified during health emergencies. For example, technologies from companies such as Google, Facebook and IBM could be leveraged to incorporate important and hard to obtain data into national surveillance systems, platforms developed by companies such as Amazon or Alibaba could be adapted and utilized to match public health challenges with solutions, and supply chain innovations developed by Coca Cola, product innovations developed Johnson & Johnson and Proctor and Gamble could be leveraged to address hard to reach target audiences. Further, private-public partnerships could work together on public health communications and messaging, data analytics, data visualization to the public, marketing and branding of global goods, among others.

Empowering the scientific community, non-traditional actors and the general public is necessary. With the growing widespread use of social media, it is important to ensure the right audiences are being engaged and provided with the correct, transparent information. As can be seen during the COVD-19 pandemic, the general public has become intimately involved in the response work. Engaging them through modes such as social media to advocate for health system strengthening activities during health emergencies strengthens our voice in this dimension. It also provides a constructive way for engagement by all sectors: private, academic, governmental, non-profit, etc. Actors in the private sector who have been paving the way in the design and implementation of these methodologies (as well as others not yet researched) can support the public health systems through bi-lateral partnerships. Building a critical mass of supporters and champions who advocate for strengthening health systems during outbreaks will not only allow for action at the grass-roots level but will build support that is necessary for policy makers to enact large-scale change through creation of associated funding mechanisms and policies.

Next Steps

Both systems thinking and creative problem-solving approaches are well-documented and established methodologies that can be replicated in a variety of settings and contexts. My work highlights the need to conduct and evaluate process mapping and design thinking methodologies in a variety of other settings, particularly outside of the African continent and in middle-high income countries. These approaches may be of particular benefit to middle and high-income countries where systems and processes have become formalized and therefore become more challenging to change and/or adjust. Organizations, which are intimately involved in both health systems strengthening activities and outbreak response such as WHO, national organizations and institutions such as the U.S. CDC and/or National Institutes of Health, state organizations including departments of health, and local and non-profit organizations could each use these methodologies during outbreaks to contribute to stronger health systems.

In addition, there is a need to understand additional outbreak and health system challenges that creative problem-solving approaches and systems thinking methodologies can be used to solve, outside of information management, surveillance, laboratory and clinical systems. Health system challenges that are further exacerbated by outbreaks and which could potentially benefit from these methodologies include vaccine delivery and cold-chain systems, electronic contact tracing systems, and disbursement of funds.

Lastly, in this body of work, only two types of methodologies were implemented during an outbreak. There are many other systems thinking and creative problem-solving methodologies that could be used but need additional research to determine their effectiveness in response and health system strengthening activities. Methodologies such as network analysis, systems analysis or eight disciplines (8D) model may be good places to start as they are relatively low cost to conduct, require limited external expertise and have proven success in numerous industries and settings (35,82,108).

For complex outbreaks in general and in particular to the current COVID-19 outbreak where there is an overwhelming number of system challenges and it is not possible to implement planning activities traditionally done during the preparedness period, national and sub-national IMS teams could take a ½ day strategic pause and identify ten challenges (five “high complexity/high impact” and five “low complexity/high impact”) which if addressed could improve the acute response but also components of a health system. Once these ten challenges are identified, one to three could be prioritized for immediate action and methodologies such as process mapping and/or design thinking could be instituted to develop short and long-term solutions. Ensuring strong external partnerships throughout this is important as there can be an influx of financial and human resources to support this in the short and long term. Following this, a quarterly meeting could be established to review the remaining challenges and adjust accordingly. As systems are inherently dynamic, revisiting the challenges and ensuring evaluation and reiteration will promote sustainability and resiliency. Further, highlighting these challenges with political leadership and the public at large, at the appropriate stages, will allow for strategic buy-in and the inclusion of resources. Additionally, it is important to celebrate the successes both internally with those that worked on the challenge as well as publicly. This will provide much-needed recognition to the teams working on the emergency as well as will allow politicians and the general public to understand behind the scene challenges.

It is imperative that public health practitioners, epidemiologists, health systems experts, data scientists/IT specialists, and researchers responding to disease outbreaks and building resilient health systems work together to test and pilot additional systems thinking and critical problem-solving methodologies. Further, inclusion of political figures, policy advisors and the general public is important to ensure engagement of and prioritization of resources that support the strengthening of health systems during outbreaks. It is through trying novel approaches, working together and remaining in a growth mind-set that we will be able to address acute and long-term challenges that impact the health of our populations.

Figure 1: Process mapping methodology

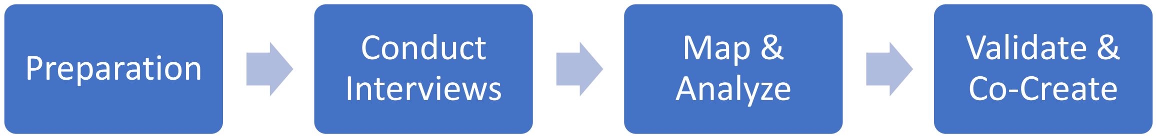
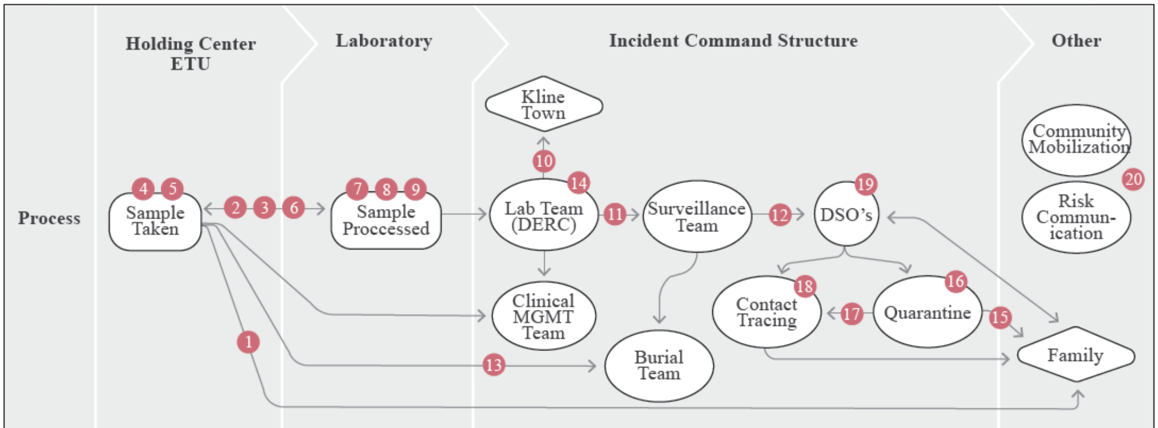
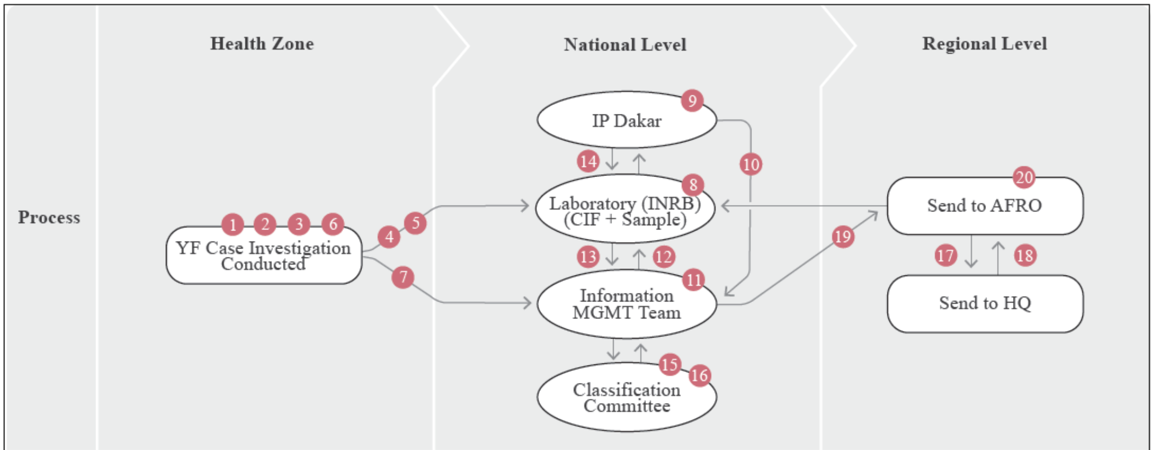


Figure 2: Process mapping exercise for Case Study 1 (Sierra Leone)



Pain Points	Holding Center ETU	Laboratory	Incident Command Structure	Other
	1 Family can't locate ill member since no link between ambulance pick-up and ETU name. 2 Samples from same patients are sent to different labs causing backlog 3 If results are not received within 48 hours, follow-up blood specimen is taken and resent 4 Long wait times in holding centre resulting in unnecessary exposure for negative patients and delayed time to treatment for the EVD positive patients 5 EVD patients being kept in ETU's longer than necessary after their recovery resulting in valuable bed space being occupied unnecessarily 6 Case investigation forms and samples were received at the laboratories without any ETU/HC location making it was difficult to relay the results.	7 Lab results are not sent in standard manner: via Excel and phone 8 Results are sent at varying times in day/night 9 Not all ETU/HC have capacity to receive electronic results	10 Lab results aren't systematically sent to Kline town for death certificates to be processed and family can't receive death benefits 11 Surveillance team receives results electronically from DERC and daily distributes via paper to Quarantine, contact tracing, DSOs and Burial teams 12 If DSO does not come to Western Command Centre in morning s/he doesn't receive result list to inform families of status 13 Burial team receives results on ad-hoc basis from Holding Centre/ETU and Surveillance team 14 None of the data is linked between pillars and ETU 15 Quarantine officers inform family of positive results when putting quarantine on home 16 Quarantine officers responsible for ensuring food gets to family, police monitoring and removal of homes but there is no link between the positive results and quarantine teams to ensure timeliness of food being distributed and removal of quarantine 17 Quarantine officers generate contact tracing list 18 Contact tracing teams don't systematically get the lists of contacts and receive from multiple sources 19 Paper results are distributed/received on an ad-hoc basis from DSO's (If DSO's don't see family members, they aren't able to relay results)	20 No link between positive results and community mobilizers and risk communica-tions and unable to target messaging and engagement

Figure 3: Process mapping exercise for Case Study 2 (Democratic Republic of Congo)



	Health Zone	National Level	Regional Level
Pain Points	1 Epi ID assigned in health zone by data managers without standardized format resulting in duplicate Epi IDs 2 Insufficient data entry staff (no data teams in Bas Uele, Kwango, Tshuapa), not enough in Kinshasa) 3 Delayed reporting of suspect cases from Rural to National levels 4 Delay in sample being shipped to laboratory; resulting in poor quality samples 5 Investigations not thorough resulting in limited information obtained for assessing laboratory confirmed cases 6 Data entered into non-standardized excel spreadsheets 7 Data inconsistently (and delayed) to national level team (phone call, excel spreadsheet emailed, etc.)	8 Only lab specific data from case investigation form is entered electronically creating new database for epi and lab 9 Samples are sent to IP Dakar for validation, storage not adequate resulting in poor quality samples 10 Delay in confirmed sample results being sent to information management team 11 Backlog of CIF to be entered into database 12 Case investigation forms were manually collected by data managers 13 Every 2 days excel spreadsheet with lab results are sent to data managers 14 Reference lab sent results to information management team and Natl Lab 15 3 different databases being used at the Classification Committee 16 Not all the relevant focal points attended the meeting regularly	17 Delay in aggregated data being sent to HQ and limited information for situation reports 18 Missing feedback loop to discuss challenges with HQ, regional and country staff 19 Missing feedback loop to discuss challenges with regional and country staff 20 No consolidated database for entire Angola/DRC outbreak for regional decision making

Figure 4: Process mapping exercise for Case Study 3 (Nigeria)

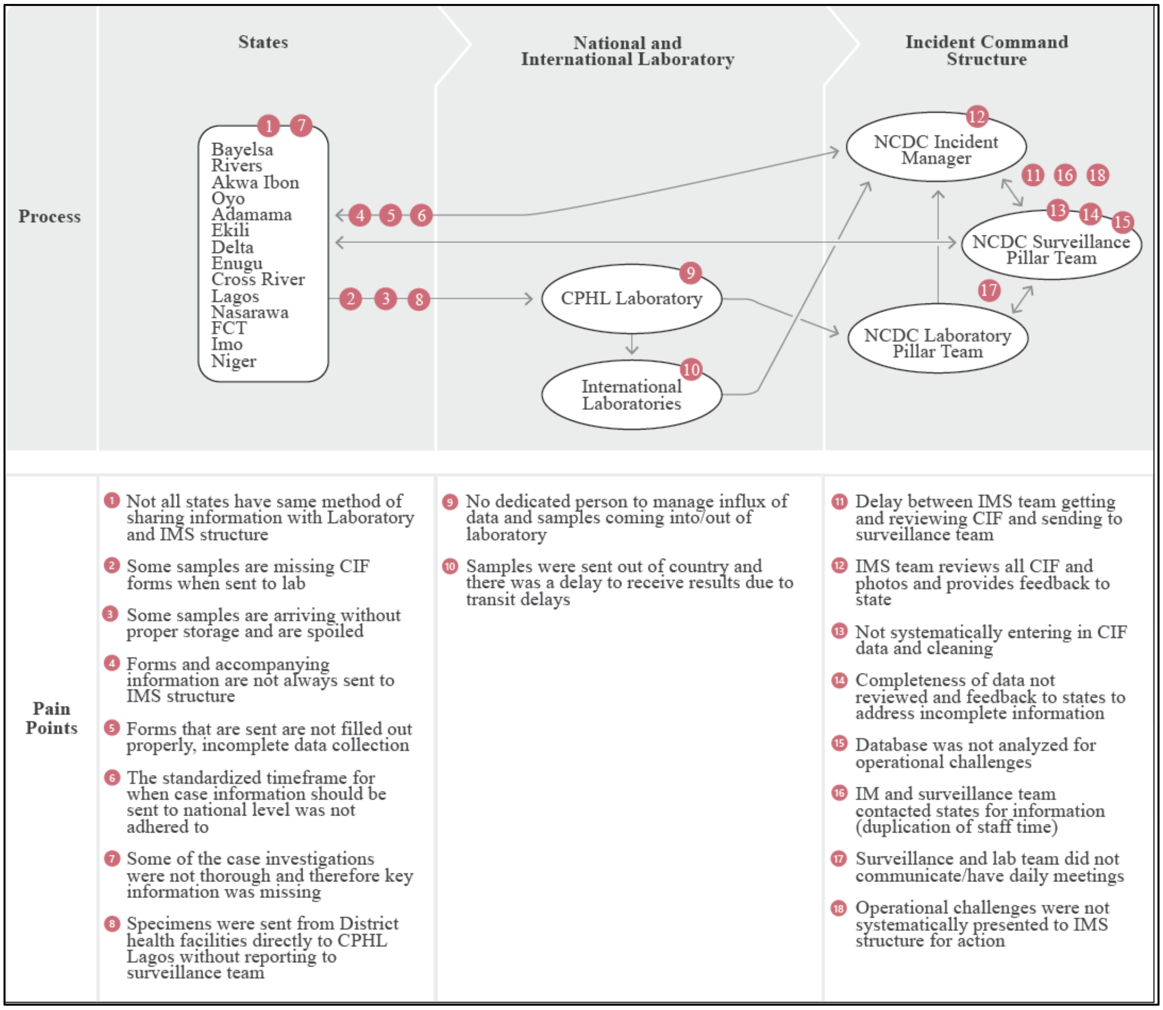


Figure 5: Defining the problem and stakeholders

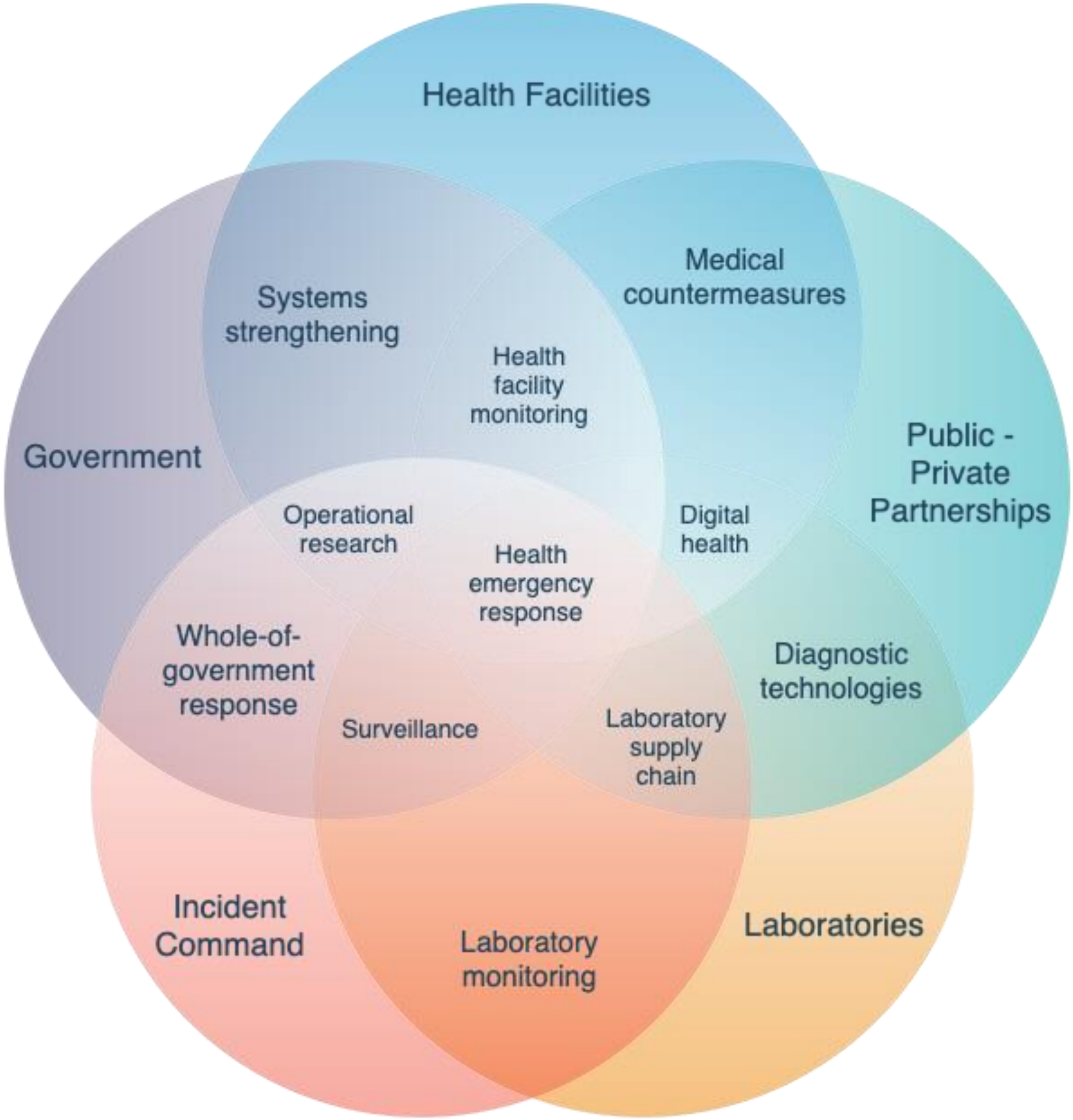


Figure 6: Design thinking methodology

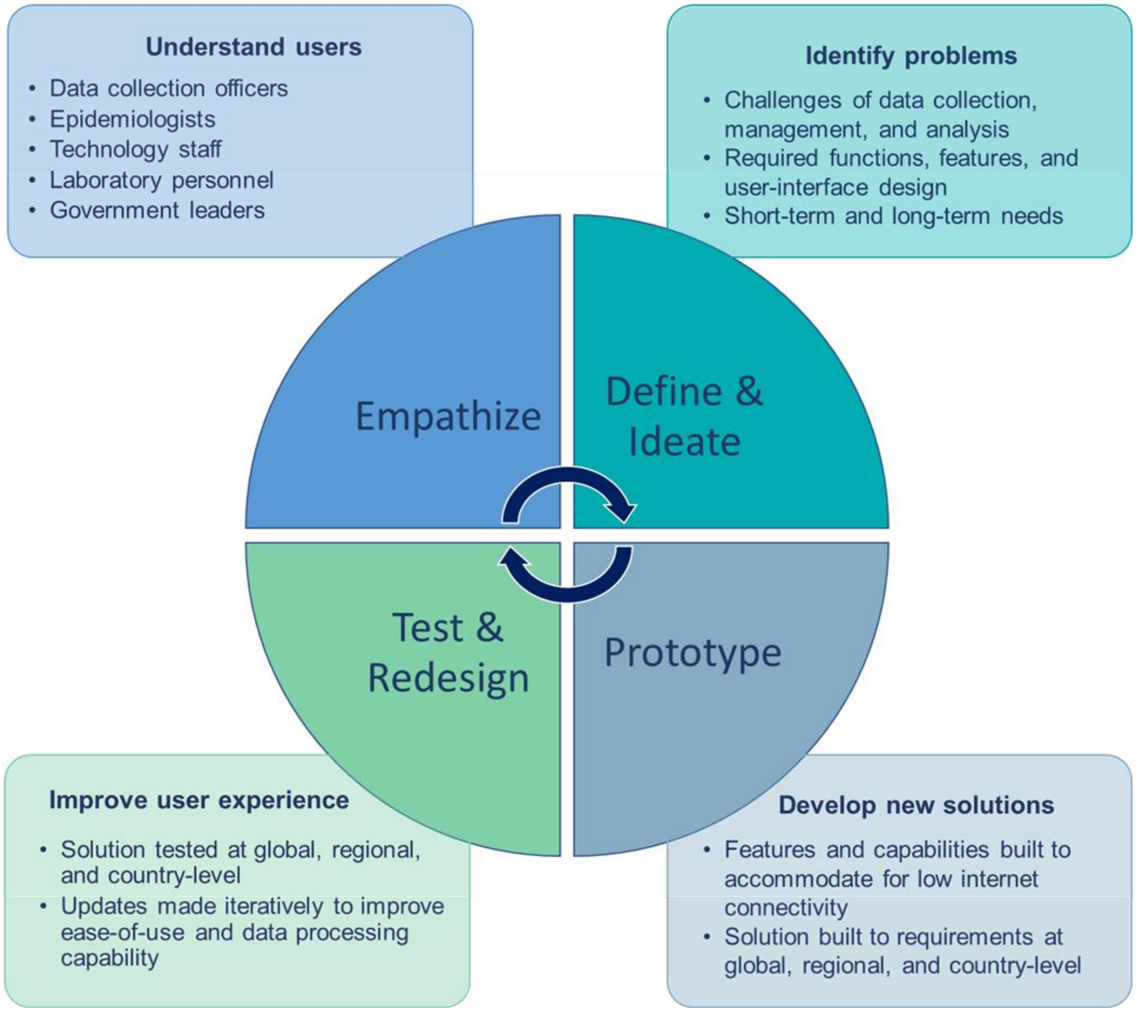


Figure 7: Mobile and fixed laboratories deployed in Guinea, Sierra Leone and Liberia since March 2014

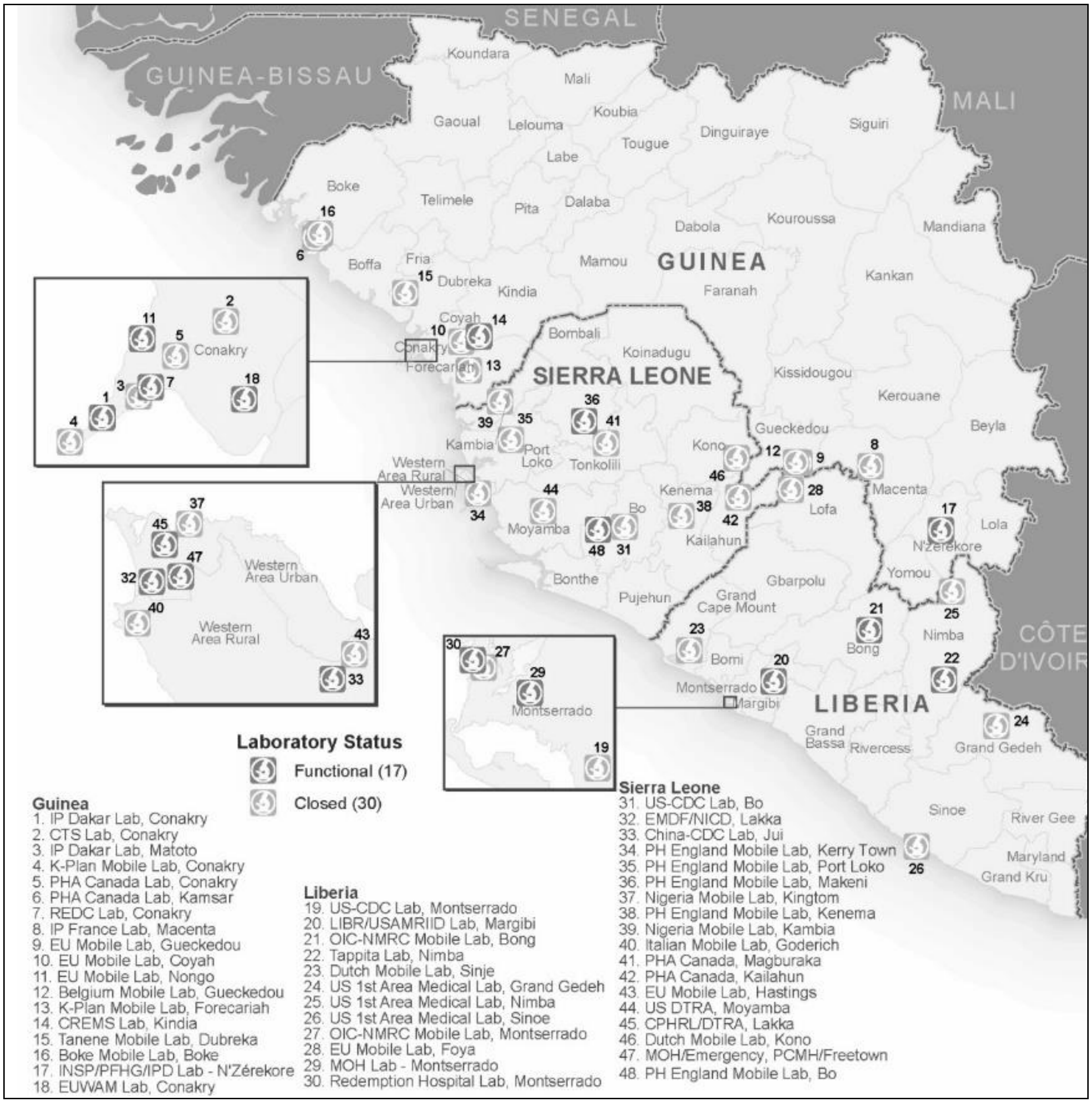


Figure 8: Data flow to and from laboratories and between levels of response

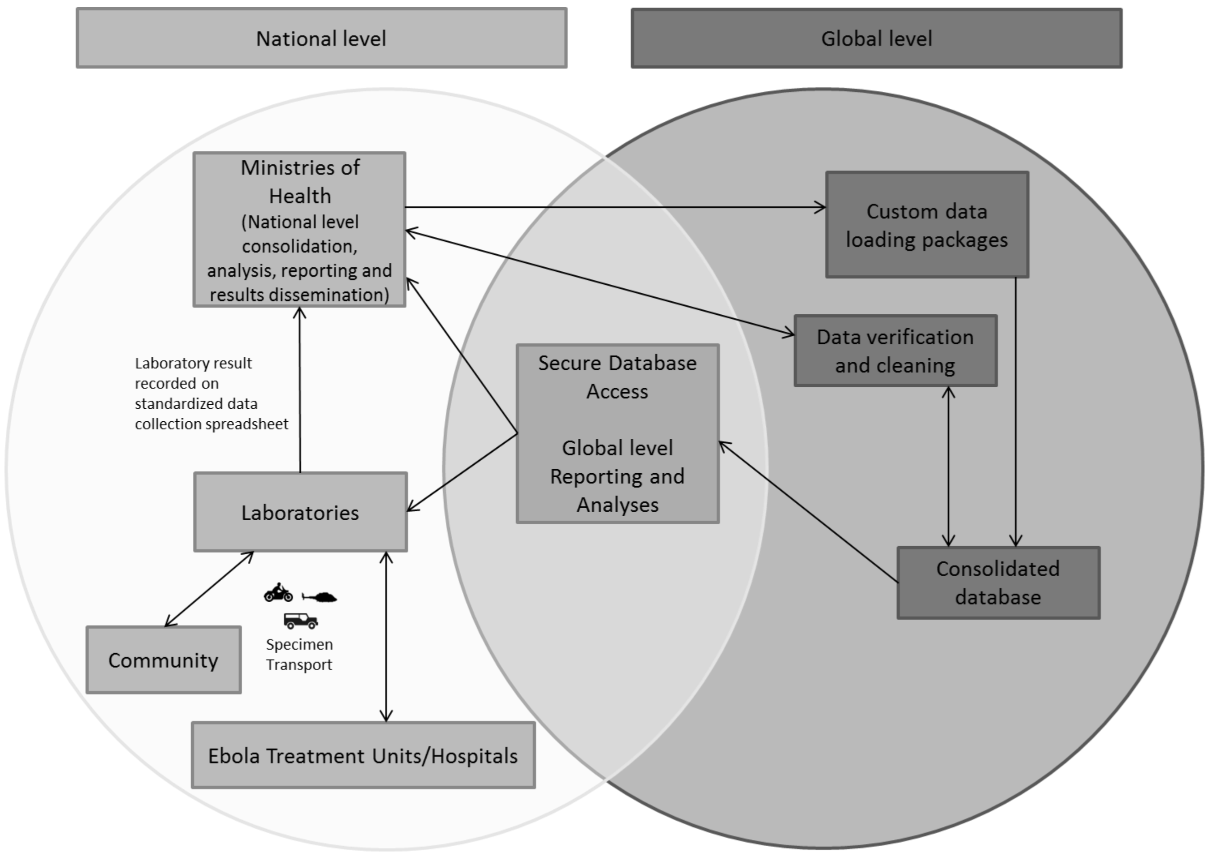


Figure 9: Data completeness in comparison to laboratory specimens tested and confirmed/probable cases in Guinea, Liberia and Sierra Leone since March 2014

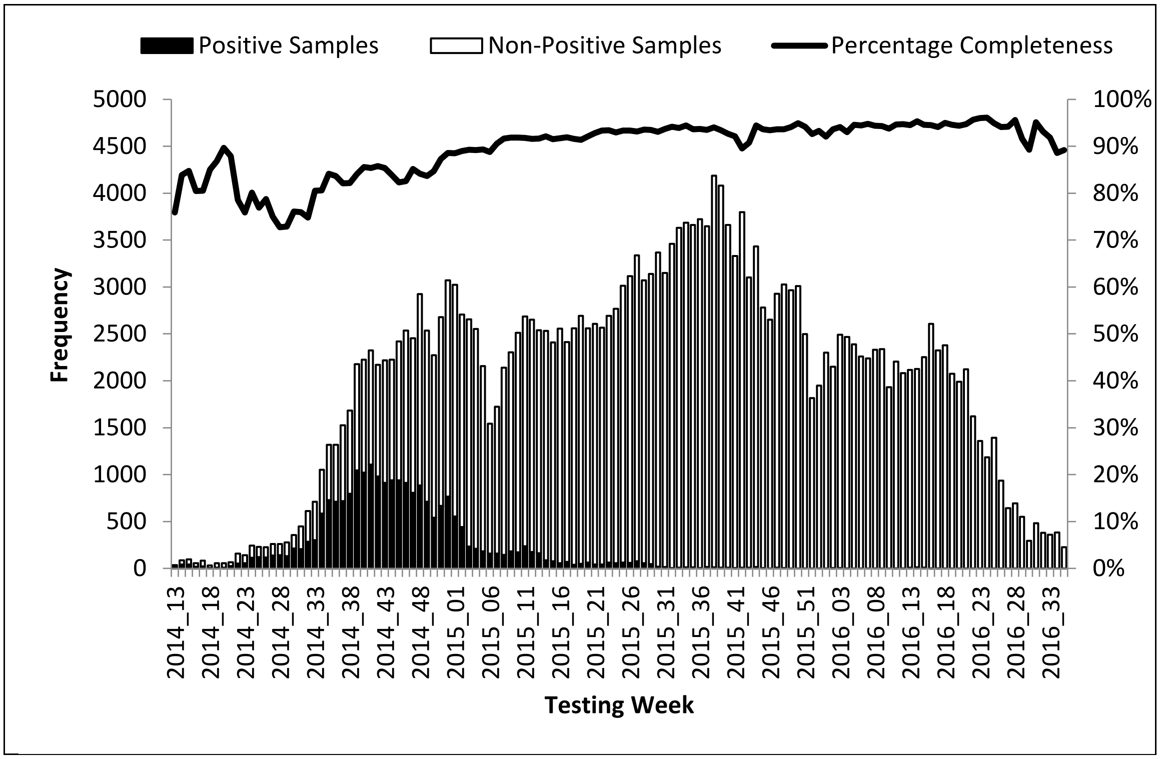


Figure 10: Example analyses created for information response activities

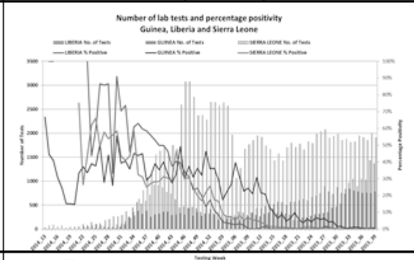
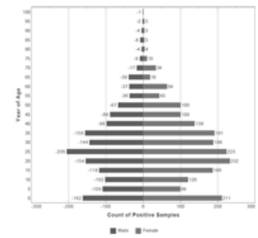
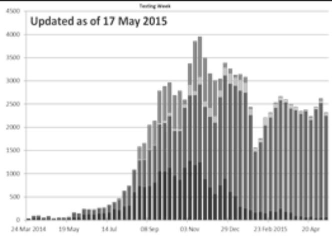
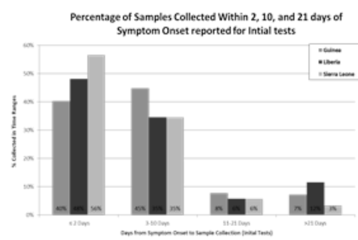
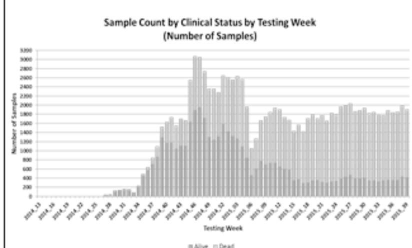
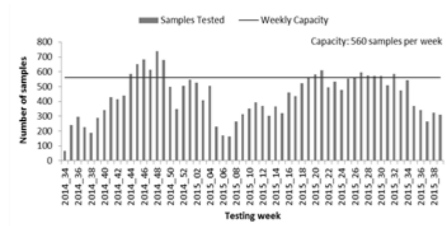
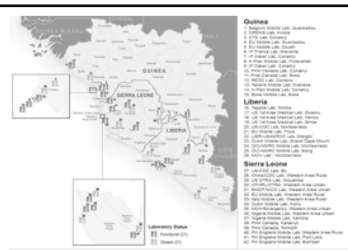
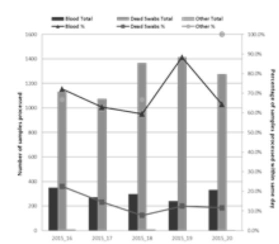
Type	Example analysis	Type	Example analysis
Positivity Rates		Demographic distributions	
Sample Count Epi Curve		Monitoring response systems	
Monitoring of clinical and community burial teams capacity		Laboratory Capacity	
Geographic distribution of laboratories		Monitoring of Laboratory systems	

Table 1: Proposed Solutions for Countries

	Challenge	Proposed Solution
Case Study 1: Sierra Leone	Result delay, Communication	train surveillance officers on how to complete the case investigation forms (CIF) and explain the implications associated with not filling them out completely
	Result delay, Information system	give each HC/ETU a unique rubber stamp with the name of the unit and an identifier so that all lab requests could be traced and training staff on proper use of the stamps
	Result delay	establish a sample distribution and routing plan
	Human resources	develop and train additional data entry and management support
	Communication	identify clear roles and responsibilities for staff at laboratories, ETU's, and HC's
	Information system	standardize data collection forms between all facilities
	Result delay	streamline the relay of results
	Human resources	hire dedicated data managers to manage the flow of results
	Information system	develop a national consolidated database

Case Study 2: Democratic Republic of Congo	Process/procedures, information sharing	decentralize activities down to a health zone level
	Process/Procedures	develop processes and procedures to improve the flow of data with roles, responsibilities, and timelines
	Information system	merge databases maintained separately by the Classification Committee, INRB, and WHO into one cleaned, central database
	Human Resources	hire a data entry clerk at the national level so that data managers and epidemiologists can prioritize the cleaning and consolidation of the database
	Human Resources	recruit and train additional data management staff to support data collection, data entry, ongoing and retrospective cleaning, consolidation of data, and data analysis
	Information sharing, system	create a Datamart to quickly upload and share the consolidated database from the WHO country office in DRC to regional and global levels

Case Study 3: Nigeria	Data collection, communication	educate all state epidemiologists about monkeypox disease and the current outbreak
	Data collection, communication	classify and provide feedback on CIFs submitted to the national level within the same day
	Information system	analyze completeness of data and report back to the State to promote the reporting of accurate and complete data
	Data collection	the laboratory would utilize a standardized lab form and send the results to the lab lead at the national level within a determined time period
	Information system	two data managers would ensure all data from the CIF were entered daily into an Epi Info database which had both lab and epi data linked and cleaned
	Information system	map data on a daily basis and report findings to understand geographic movement
	Communication	a daily lab/surveillance/data meeting would be established to address all technical issues
	Communication	develop a standardized PowerPoint slide deck to ensure key points were communicated during the daily incident management meeting (promote information sharing and collaboration)

Table 2: Database field completeness for EVD affected countries

Field Type	**% Completeness**
Laboratory name	**100.00%**
Unique patient identifier	**92.30%**
Laboratory sample identifier	**96.90%**
Name	**99.10%**
Surname	**95.70%**
Age	**94.20%**
Sex	**86.90%**
Country	**100.00%**
Location of specimen taken	72.70%
Province, region, or county	**91.30%**
District or prefecture	**90.70%**
Chiefdom, sub-prefecture, or village	63.70%
Initial or repeat test	**81.10%**
Specimen test sequence (1st test, 2nd, etc.)	10.40%
Date of patient symptom onset	54.80%
Date of patient hospitalization	5.60%
Date of specimen collection	**92.70%**
Date of specimen received in laboratory	54.70%
Date of test performed	**97.70%**
Date of patient death[††]	8.60%
Type of specimen collected	**95.70%**
Patient clinical status at time of test[††]	**97.00%**
EVD test result	**99.60%**
EVD test Ct value	13.60%
Referral centre	68.60%
Non- EVD test results (Malaria, Lassa, IgM, IgG, Ag, Piccolo)	4.20%
Patient contact information, address, profession	8.90%
Symptoms	1.30%
Comments	41.80%

[†]Most utilized fields (completeness greater than 75%) highlighted in bold.

[††]Patient clinical status and dates of death were documented as of the time the sample was taken.

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